ASPECTS OF DOG OWNERSHIP AND CANINE RABIES CONTROL IN AFRICA AND ASIA

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In memory of

Dr Magai Timothy Kaare

'Mzee'

DECLARATION

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

Darryn Knobel

whole good. Households headed by younger occupants were less likely to own dogs, as were households living in attached houses or flats. Hindu and Muslim households were less likely to own dogs than Buddhist or Christian ones. Households in which respondents had a more positive attitude towards dogs were more likely to own dogs.

An item scale to measure attitudes towards owned dogs in Tanzania was developed. Twelve 5-point Likert scale items were administered to 824 dog owners across the 12 study sites in Tanzania. Two subscales were derived, representing the acceptance of dogs as equals and physical interactions with household dogs. Both subscales showed acceptable levels of reliability and concurrent validity, although the latter estimates were found to be influenced by interviewer identity. Male respondents had significantly higher scores on both subscales than females, and Muslim respondents showed more positive attitudes towards dogs as equals than did Christians. Among those respondents who were also the heads of their households, those whose dogs were vaccinated against rabies had a more positive attitude towards dogs as equals. In Colombo, 18 7-point Likert scale items were administered to 273 randomly-selected households. Dog owners had significantly higher scores than non-owners. Religion was the main predictor of people's attitudes towards dogs, with Buddhists and Christians having a significantly more positive attitude towards dogs than either Hindus or Muslims. There was some evidence to suggest that respondents' attitudes may influence behaviour towards and thus welfare of owned dogs. Dogs owned by respondents with a higher attitude score were more likely to be dewormed and less likely to suffer from skin conditions such as mange.

Data on a vaccination campaign in the face of a rabies outbreak in endangered Ethiopian wolves is presented. Ethiopian wolves on the periphery of the outbreak area were trapped to administer a dose of injectable rabies vaccine and to assess the magnitude and duration of the immune response. All wolves sampled one month after vaccination had protective levels of serum antibody titres. A booster dose administered within one to six months appears necessary to maintain these levels. Females were less likely to be trapped than expected, if dispersing females were included in the population. Animals captured in the first trapping session were more likely to be recaptured if the pack was trapped again than those that were not. The intervention was successful in halting the spread of the rabies outbreak and had few short-term impacts on the population of wolves and non-target species.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This volume presents a coherent body of work conducted while I was registered as a part-time student for the degree Doctor of Philosophy (by research). The common thread running through the work, connecting the various chapters, is rabies – specifically, canine rabies in the developing countries of Africa and Asia. The first chapter introduces the topic and sets the scene for the remainder of the text. Historical and current issues relating to the control of dog rabies are discussed, as are the impacts that the disease (and attempts at its control) has on multiple fields including public health, the conservation of endangered canids and the welfare of dog populations. Chapter 2 presents an attempt to quantify the true burden of this chronically under-reported disease in the worst-afflicted areas, in terms of human mortality, years of life lost to the disease and its economic impact in the African and Asian regions. Chapters 3-6 focus on aspects of human-dog interactions in two countries from these regions, Tanzania and Sri Lanka. The realisation that in Tanzania (and probably in other sub-Saharan African countries) the vast majority of dogs can be characterised as 'owned', and that many human rabies cases are derived from dogs over whom at least one household would (or might until recently) have claimed at least some degree of ownership or responsibility, prompted research into the patterns and factors predicting dog ownership in a variety of socio-cultural settings in this country (Chapter 3). At the same time I realised that, although vast amounts of work had been done on the topic in the industrialised nations of the world (where pet ownership is a billion-dollar industry), very few studies had looked at the attitudes of people towards domestic dogs in the developing regions of the world, and none in sub-Saharan Africa, despite the potential relevance of this to the field of rabies control. Chapter 4 presents the development and application of a tool to quantify attitudes towards dogs among owners from a large cross-section of Tanzanian society, and briefly explores the implications for rabies control and dog welfare. Chapters 5 and 6 cover similar issues of dog ownership and attitudes in an urban Asian environment (Colombo, Sri Lanka). Although this work was done as part of a larger project on humane dog population management by the World Society for the Protection of Animals (WSPA) and the Blue Paw Trust in Colombo, the aspects presented here were designed and implemented by me, refining the methods used to address the same questions previously in Tanzania. Although still related to the theme of dog rabies, Chapter 7 shifts the focus to the impact of disease spill-over into a population of critically-endangered canids, the Ethiopian wolves of the Bale Mountains, and discusses the management steps taken to mitigate this impact.

The reader will notice that this thesis is formatted as discrete chapters, each prefaced by an abstract and introduction and followed by a discussion, rather than extracting and presenting these as separate chapters at the beginning and end of the thesis (although an overall synthesis of the work is presented in Chapter 8). Chapter 1, which serves as an introduction to the topic, was published as a book chapter in the new edition of 'Rabies' (see citation on p. 1), and at the time of submission of this thesis, all the remaining chapters, with the exception of 5 and 6, had been published or accepted for publication in peer-reviewed journals. The results of Chapter 5 will be published in combination with additional work by colleagues on the demography and welfare of the unowned dog population in Colombo, and Chapter 6 is being finalised for submission to a peer-reviewed journal. In all the work presented in this thesis, I was primarily responsible for the design of the studies, supervision of data collection and entry by research assistants, statistical analysis of the data, and drafting of the manuscripts. Appendix 3 contains additional manuscripts on the subject of rabies co-authored by me during the course of this PhD.

1 CHAPTER 1: DOG RABIES AND ITS CONTROL

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Sections of this chapter were co-written with Dr Magai Kaare (Section 1.10) and Dr Eric Fevre (Section 1.12). The remaining sections were exclusively my work, based on discussions with the above-mentioned co-authors.

1.1 Introduction

Rabies is caused by a number of genetically closely related viruses belonging to the genus Lyssavirus, of which the type species is rabies virus. A true generalist pathogen, rabies virus has been isolated from nearly all mammalian orders (Rupprecht *et al.*, 2002), and the disease occurs on all continents except Antarctica (Warrell and Warrell, 2004). Although rabies can infect all mammals, only a few mammalian species are known to act as reservoirs of the disease, with domestic dogs being the major reservoir throughout Africa and Asia (Rupprecht *et al.*, 2002). The association between the bite of a 'mad' dog and rabies has been recognised since antiquity (reviewed by Neville, 2004), and rabid dogs are still responsible for the vast majority (>90%) of human deaths from rabies worldwide (WHO, 1999; http://globalatlas.who.int/globalatlas). This can be true even in some areas where wildlife species are the rabies reservoir, as the proximity of dogs to humans provides a link in transmission between wildlife and people.

1.2 The Burden of Canine Rabies

More than 99% of all human deaths from rabies occur in Africa and Asia (WHO, 1999; http://globalatlas.who.int/globalatlas). Canine rabies is reported in many countries of Africa and Asia, and is likely to be maintained endemically in areas where the dog density exceeds the threshold for persistence, considered to be about 4.5 dogs/km^2 (Brooks, 1990; Bishop, 1995; Cleaveland and Dye, 1995; Kitala *et al.*, 2002) (Figure. 1.1 and 1.2). In these areas, the disease is responsible for some 55 000 human deaths each year (Knobel *et al.*, 2005). Globally dog rabies kills more people than yellow fever, dengue fever or Japanese encephalitis, and more than 7 million people are potentially exposed to the virus annually (Coleman *et al.*, 2004; Knobel *et al.*, 2005), leading to a high demand for expensive post-exposure prophylaxis (PEP).

The high demand for PEP resulting from dog rabies exerts a substantial economic burden in Africa and Asia, not only as a result of the high costs of the human vaccine and immunoglobulin that are required for prevention, but also because of considerable indirect (patient) costs associated with travel and income loss (Knobel *et al.*, 2005). The total (direct and indirect) costs of PEP accounts for 5.8% of annual *per capita* gross national income in Africa ($40 per treatment) and 3.9% ($49 per treatment) in Asia (Meltzer and Rupprecht, 1998; Knobel *et al.*, 2005). Additional economic losses associated with dog rabies accrue through livestock deaths which, although poorly quantified, may be significant. Socioeconomic factors influence the distribution of rabies cases, with people who are poor, less well educated and those living far from treatment centres least able to access prompt and appropriate PEP. Children of less than 16 years of age are the major victims of dog rabies, as they are more often bitten by dogs than adults, and when bitten, are frequently bitten on the head and neck, sites which carry a much higher risk than bites to other parts of the body (Pancharoen *et al.*, 2001; Cleaveland *et al.*, 2002; Knobel *et al.*, 2005; Févre *et al.*, 2005). Although safe and highly effective cell-culture vaccines are available for PEP (WHO, 2004), the high cost

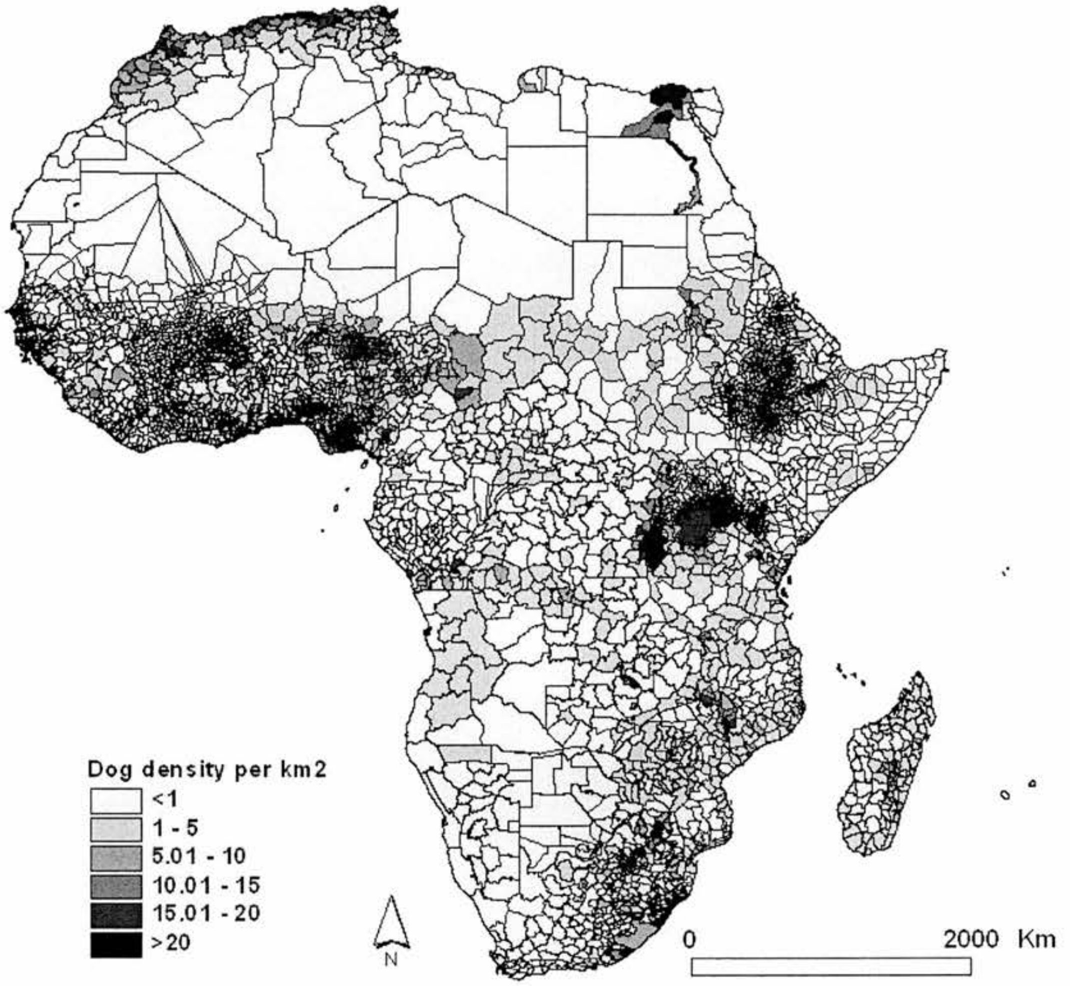

Figure 1.1. The density of domestic dogs in Africa, using human densities derived from an Africa population density dataset and a regional human:dog ratio of 12.3. Polygons are subnational administrative boundaries, as per Diechmann (1996a).

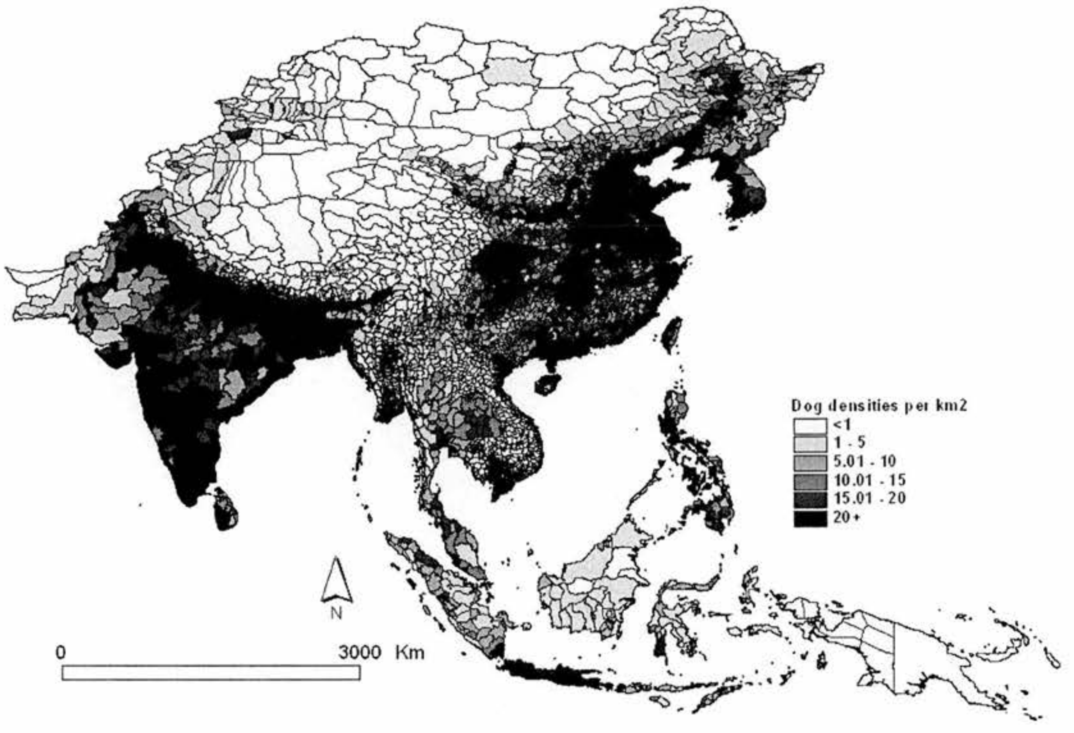

Figure 1.2. The density of domestic dogs in Asia, using human densities derived from an Asia population density dataset and a regional human:dog ratio of 9.5. Polygons are subnational administrative boundaries, as per Diechmann (1996b).

of treatment is resulting in the continued use of cheaper nerve-tissue origin vaccines in parts of Asia and Africa, with the attendant risks of severe neurological side-effects.

An additional disease burden relating to canine rabies is the morbidity associated with bites from rabid dogs, which can often result in severe injury. The incidence of bite injuries from suspected rabid dogs in various communities in Africa and the Middle East has been estimated as 40-288 bite victims/100 000 people (Zeynali *et al.*, 1999; Kitala *et al.*, 2000; Cleaveland *et al.*, 2002; Févre *et al.*, 2005). First-aid care such as washing the bite wound with soap and water can significantly reduce the risk of rabies infection; however, many bite victims do not receive even this simple treatment (Parviz *et al.*, 1998). Aside from the physical trauma, the psychological impacts of rabid dog bite injuries are not trivial. In many parts of Africa and Asia, the post-exposure treatment given to animal bite victims is deficient by all World Health Organization (WHO) standards (Parviz *et al.*, 1998; Févre *et al.*, 2005). Access to human rabies PEP is often undependable, rabies immunoglobulin is unavailable, and the provision of a full course of vaccination is not only extremely costly but also logistically demanding. As a result, PEP is often unreliable and the bite from a suspect rabid dog can cause great distress, with months of anxiety as the individual awaits an uncertain outcome. Preliminary work carried out in Tanzania revealed that people are more concerned about the potential threat from rabies than from malaria, despite the higher prevalence of the latter (M. Kaare, unpublished data). When human cases do occur, the distressing clinical signs and invariably fatal outcome result in considerable psychological trauma for families, communities and health-care professionals involved with the victim (Warrell and Warrell, 2004).

Further consequences of dog rabies relates to animal welfare and conservation. While the effects of canine rabies on public attitudes and treatment of dogs have been poorly investigated, there is no doubt that in areas where canine rabies is endemic, fear of the disease has important implications for animal welfare, with suspected rabid dogs and unknown, stray dogs often killed inhumanely in an attempt to control rabies and human exposure. Infectious disease is also increasingly recognized as a threat to several endangered carnivore species (Funk *et al.*, 2001; Woodroffe *et al.*, 2004). Population viability analyses indicate that canine rabies poses an important extinction risk for both Ethiopian wolves *Canis simensis* (Haydon *et al.*, 2002) and African wild dogs *Lycaon pictus* (Ginsberg and Woodroffe, 1997; Vucetich and Creel, 1999), particularly in small- and medium-sized populations. Both these endangered species have suffered high mortality during previous rabies outbreaks (Gascoyne *et al.*, 1993; Kat *et al.*, 1995; Sillero-Zubiri *et al.*, 1996, Randall *et al.*, 2004).

Despite the multitude of problems associated with dog rabies and the considerable disease burden, the disease remains widely neglected and uncontrolled throughout much of Africa and Asia. In many regions of sub-Saharan Africa, the past three decades have seen a dramatic increase in the number of reported cases of the disease, and in the range of species in which canine rabies has been recorded (Perry, 1995; Cleaveland, 1998). Many factors are likely to have contributed to this, including the enormous increase in domestic dog populations, which are typically growing at a rate of 5-10% per annum (Kitala and McDermott, 1995; Cleaveland, 1996; Laurenson *et al.*, 1997), and the high mobility of human (and dog) populations. In many areas, these factors are compounded by deteriorating infrastructure available to veterinary services for effective disease control, allowing rabies outbreaks to spread unchecked. The escalation in rabies cases in Africa and Asia poses considerable challenges and, in this chapter, discussion of issues relating to dog rabies control will therefore focus primarily on these regions of the world.

1.3 Historical Perspectives On Dog Rabies Control

Successful canine rabies control or even elimination programmes have been carried out since as early as the latter half of the 19th century. In 1831 a bill was drafted in the United Kingdom 'to prevent the spreading of canine madness' (Fooks *et al.*, 2004) and enforcement of this legislation, which included the muzzling of dogs, restriction of their movement, and the destruction of strays and rabid dogs, along with a strict import control policy, led to the elimination of terrestrial rabies from that country in 1902 and again in 1922, after its reintroduction in 1918 (Muir and Roome, 2005). These measures – movement and contact restrictions, notification and observation of cases, tracing of contacts, and the killing of rabid, suspect-rabid and free-roaming dogs not in compliance with legislation – constitute the so-called 'classical' methods of canine rabies control. An additional and powerful control tool came in the 1920s, with the advent of the first effective veterinary vaccines against rabies (Umeno and Doi, 1921). Japan, in 1921, was the first country to apply mass vaccination of dogs, but it was not until 1957 that rabies was eventually eliminated from within its borders (WHO 1966). The first field trials to demonstrate that canine rabies could be eliminated through a combination of mass vaccination and classical control measures were in fact carried out in Hungary in 1937. This country went on to conduct the first successful national rabies control campaign, from 1939 to 1944 (Manninger, 1968). In the 1950s, several other countries followed this example, with canine rabies being eliminated from Hong Kong in 1956 (Cheuk, 1969) and Taiwan and Portugal in 1961 (WHO, 1966). Early success in Malaysia, where the disease was quickly brought under control following the initiation in 1952 of compulsory vaccination of dogs and destruction of strays (Wells, 1954), indicates that it is not only in the more developed countries that dog rabies control is possible. In Africa, both Zimbabwe (Shone, 1962) and Uganda (Arvo and Kaumba, 1971) reported dramatic declines in canine rabies cases over the ten years prior to 1961.

Although dog population control through the killing of strays, either by shooting or poisoning, commonly forms part of national rabies control strategies, current consensus suggests that the persistence of this approach is due to a number of erroneous assumptions and poor insight into the epidemiology of rabies and the ecology of dog populations (WH0, 1992a). A dearth of successful canine rabies control programmes during the 1970s, and a growing awareness of the lack of information on the dynamics of dog populations (particularly in comparison to the increasing body of knowledge on fox ecology in relation to the rise of sylvatic rabies in Europe at that time), prompted the WHO in 1984 to instigate three research projects into the ecology and population dynamics of dogs in developing countries. The sites chosen were in Sri Lanka, Ecuador and Tunisia, and the results were to significantly change the approach to canine rabies control at a national and international level (WHO, 1988). They showed that, in order to attain a lasting reduction in dog population size, lethal control programmes would need to remove 50-80% of the population each year. In Sri Lanka, where sustained dog elimination campaigns had been conducted since 1977, researchers found that, despite removing between 35 000-50 000 dogs annually, these programmes were only reaching 5% or less of the targeted dog population. A concerted effort in Guayaquil, Ecuador, which resulted in the removal of 24% of the dog population over a period of 12 months, was found to have no lasting impact on the size of the dog population, or on the incidence of canine rabies. In fact, the community response to dog elimination campaigns in Guayaquil and elsewhere has been to buy new puppies or to adopt free-roaming dogs that move into the area to fill the vacant niche. Because these dogs are mostly unvaccinated, and because the elimination campaigns themselves often remove vaccinated dogs (4% of killed dogs in the Sri Lankan study were found to have demonstrable serum rabies virus neutralizing antibody titres), the net result of dog elimination campaigns is often to reduce the proportion of immunized individuals in a population, and thus decrease the level of 'herd immunity'. The WHO report (1988) concluded that not only did dog elimination programmes not have any significant long-term effect on dog population sizes, they also incited animosity towards rabies control personnel in local communities, resulting in decreased cooperation during mass vaccination campaigns. This viewpoint is further supported by results of recent campaigns to control dog rabies in Flores, an island in Indonesia that had previously been rabies-free, and in which 295 565 dogs were killed over a four year period as a means to tackle a rabies epidemic. While this impacted on rabies in some areas of the island, it was not successful at preventing the further spread of rabies amongst both dogs and humans (Windiyaningsih *et al.*, 2004), in large part due to the unpopularity of the culling scheme, as most dogs on Flores are owned (Bingham, 2001). By May 2004, 48% of the island's dog population had been destroyed, but rabies transmission continued.

The results of the WHO (1988) and other studies led the WHO Expert Committee on Rabies to the following conclusion in 1992 (WHO, 1992): '.... the Committee recommended drastic changes in rabies control policies as compared with those previously adopted and practised by most national authorities and communities. There is no evidence that removal of dogs has ever had a significant impact on dog population densities or the spread of rabies. The population turnover of dogs may be so high that even the highest recorded removal rates (about 15% of the dog population) are easily compensated for by increased survival rates. In addition, dog removal may be unacceptable to local communities. Therefore, this approach should not be used in large-scale control programmes unless ecological and sociocultural studies show it to be feasible.'

1.4 Dog Accessibility

The WHO-instigated studies also overturned a number of other assumptions relating to the accessibility of dogs to vaccination. Previously it had been believed that, in any given human social or economic setting, 30-60% of dogs were 'stray' animals, which could not be vaccinated (Bögel and Joshi, 1990). Researchers, however, found that in each of the three study areas most dogs were associated with either one or several households. In Sri Lanka, less than 10% of the total observed dog population was unowned, while in Tunisia, only 7% of dogs were described as 'feral'. No dogs unassociated with any household could be identified in the study in Guayaquil. The authors of the final report stated that 'whether owned or unowned, dogs which are not catchable by at least one person are rare and represent generally less that 15% of the dog population'. Similarly, Bögel and Joshi (1990) concluded that 86-97% of dogs in four areas of the Kathmandu Valley, Nepal, were accessible to parenteral vaccination.

A new and important concept in the control of canine rabies thus emerged: that of dog accessibility (Bögel, 2002). Before this concept could be more fully explored however, it was necessary to revisit and clarify the definitions applied to different segments of the dog population, in light of the recent findings. Previous terms such as 'pet', 'owned', 'feral' or 'stray' were thought either context-specific or ecologically irrelevant. New definitions were proposed, based on two quantifiable parameters: the level of a dog's dependency on humans and the level of its restriction by humans (WHO, 1988). The first of these refers to the *intentional* provision of those needs, such as food, shelter and care, necessary for the survival and well-being of the dog. Although it was recognised that this dependency of dogs on humans was a gradient ranging from total dependency to none, the following three categories of dependency were proposed:

- Full dependency – the dog is given all of its essential needs intentionally by humans

- Semi-dependency – the dog is given some of its essential needs intentionally by humans
- No dependency – the dog is given none of its essential needs intentionally by humans

The second parameter, restriction by humans, refers to the control of any contact, association and communication with other dogs and people, either through physical restriction (e.g. confinement to premises, leashing) or through direct supervision and control when outside the premises. Again, three categories of restriction are recognised:

- Full restriction – fully restricted or supervised
- Semi-restricted – movements and associations only partially restricted
- No restriction – not subject to any restriction whatsoever

The use of these two parameters gives rise to a matrix classification system (Table 1.1), which reveals four broad categories of dogs:

- Restricted dog – fully dependent of their owners and fully restricted or supervised
- Family dogs – fully dependent of their owners, but movement and contacts only partially restricted
- Neighbourhood dogs – partially dependent on the intentional fulfilment of basic needs by humans, but subject to only partial or no restriction
- Feral dogs – independent of intentional human provisioning and unrestricted

Table 1.1. Dog categorisation matrix and index of accessibility* to parenteral vaccination

	FULLY RESTRICTED	SEMI-RESTRICTED	UNRESTRICTED
Full dependency	Restricted dog +++	Family dog ++	
Semi-dependency		Neighbourhood dog +	Unrestricted dog +/-
No dependency			Feral dog -

*Index of accessibility is an assessment of the typical ease of accessibility of dogs within each category to parenteral vaccination, ranging from very easily accessible (+++) to inaccessible (-)

Missing from this classification are the terms 'owned' or 'stray' dog. Although long employed in rabies control campaigns, reference to 'stray' dogs was considered misleading, as under the new classification system a stray dog could be a feral dog, an unrestricted neighbourhood dog, or a free-roaming family dog. Dogs in the latter two categories are accessible through one or more reference households. The WHO recommended that the term be reserved for application to dogs not in compliance with local rabies control ordinance, for example those not vaccinated, on a leash, muzzled or confined. Similarly, the term 'owned dog' was deemed ecologically irrelevant, appropriate only in connection with certain administrative measures applied to dogs through their owners, such as licensing, taxation or vaccination.

1.5 Vaccination Coverage

But has this improved understanding of dog accessibility translated into improved control of canine rabies through mass vaccination coverage and, importantly, a reduction in the number of human exposures to and deaths from the disease? The results of an array of studies conducted in different socioeconomic and cultural situations suggest that it has. In Nepal, Bögel and Joshi (1990) demonstrated that 75-80% of dogs in a suburban area near Kathmandu could be vaccinated, during a month-long campaign incorporating fixed 'central point' vaccination stations and follow-up house-to-house visits. Using similar techniques, and specifically engaging the help of children over the school-holiday period to bring their dogs to the vaccination stations and to help in identifying dog-owning households, Perry *et al.* (1995) achieved a vaccination coverage of 68-75%

in a densely-populated suburb of Nairobi, Kenya. Comparable coverage levels (64-87%) were attained in three study areas of N'Djaména, Chad with the use of central-point stations kept open for 1-2 days (Kayali *et al.*, 2003). The number of inaccessible dogs was considered to be less than 8% of the total dog population in that city. In Thailand, which established a national rabies control programme in 1995 with the goal of being rabies-free within five years, mass parenteral vaccination reached 64-78% of the approximately 100 000 dogs in the canine-rabies endemic province of Petchabun (Kamoltham *et al.*, 2003). Notable success in reducing human and dog rabies has been achieved in Central and South America by the programme for the elimination of canine rabies based on mass dog vaccination, initiated and co-ordinated by the PAHO/WHO Regional Office for the Americas (WHO, 2004; Belloto, 2005). A key factor in these successes has been the leading role played by the various Ministries of Health or their equivalents, emphasizing the importance of intersectoral collaboration for effective rabies control. In addition, efforts were coordinated through the designation of a national 'rabies day', during which community resources are mobilised locally to allow synchronization of dog vaccination campaigns nationwide (Belotto, 2005).

A vaccination coverage of between 60 and 80% has been shown to result in significant decreases in dog rabies incidence and human exposures in rural Tanzania, where central point dog vaccination campaigns were conducted annually between October 1996 and February 2001 reaching 65, 61, 71 and 74% of the dog population over the four years. As a result, the incidence of dog rabies declined by 97% after the second campaign (Cleaveland *et al.*, 2003) with a concomitant decrease in the incidence of human bite injuries from suspected rabid dogs and thus a significantly reduced demand for human post-exposure rabies treatment. In conjunction with rabies awareness campaigns and the increased accessibility of low-cost human intradermal post-exposure treatment, mass dog vaccination in Petchabun province of Thailand, begun in 1996, reduced human rabies deaths to zero between 1999 and 2001 (Kamoltham *et al.*, 2003).

Although parenteral vaccination has been the mainstay of dog rabies control worldwide, the accessibility of dogs to parenteral vaccination is not uniformly high in all areas. Nearly half of all unrestricted but owned dogs in some rural areas of Turkey could not be caught by their owners (WHO, 1992b). During a house-to-house vaccination campaign in the Philippines, teams found that only 10% of eligible dogs could be caught and restrained without difficulty (Estrada *et al.*, 2001). A similar phenomenon has been observed in pastoralist communities in East Africa and in rural areas of Ethiopia, where dogs are kept to raise the alarm in the event of livestock raids by hyaenas and other predators. Central point vaccination campaigns habitually result in low turnout, while during house-to-house visits owners are often reluctant or unable to handle household dogs (Laurenson *et al.*, 1997a; Coleman, 1999). Low accessibility in these areas appears to be the product of a human:dog relationship characterised by a low level of care and a lack of perceived value in an individual dog (although dogs as a whole may have generic worth). Poor awareness of rabies risks and control measures, and socio-cultural factors such as religion may also contribute. Accessibility is also limited by the remote and highly-dispersed nature of pastoral communities. In Tanzanian and Kenyan pastoral (Maasai) communities, for example, a central point parenteral strategy achieved less than 15% coverage (Cleaveland, 1996; Coleman, 1999). Given the limited ability of many governments to deliver sustainable veterinary services to remote pastoral locations, the community-based animal health worker (CAHW) approach has emerged as an alternative veterinary service model. CAHWs have been successfully used for rabies vaccination in remote pastoral communities in Tanzania, which in combination with a centralized strategy achieved coverage levels of up 86% (Kaare, unpublished data). The combined CAHW-central point approach was also shown to be more cost effective than other conventional approaches, such as house-to-house, central point and their combinations. In another approach, Zinsstag *et al.* (2005) showed that joint human and animal vaccination programmes in pastoral areas of Chad reduced delivery costs by 15%. Such an approach could easily incorporate vaccination of dogs against rabies.

1.6 The Epidemiological Theory of Dog Rabies Control

Failure of dog vaccination to control rabies outbreaks has been noted in some areas where relatively high coverage was achieved (e.g., Mexico: Eng *et al.*, 1993). A brief examination of the theoretical basis for the design of vaccination programmes may clarify some reasons for programme failure, and provide managers with guidelines for successful implementation. Prevention of rabies outbreaks through vaccination is achieved by reducing the density of susceptible (i.e. non-immune) dogs sufficiently so that the basic reproduction number (R_0) in the population falls below one. This parameter is defined as the number of secondary cases arising from a single primary case introduced into a completely susceptible population (Anderson and May, 1991). If

$R_0>1$, each primary case will, on average, produce more than one secondary case and the infection will spread exponentially through the population, leading to an epidemic. Conversely, when $R_0<1$, each primary case will, on average, produce less than one secondary case and, although some secondary cases may occur, the infection will tend to die out without a major epidemic (Woolhouse *et al.*, 1997a). Several studies of canine rabies outbreaks in dogs have shown this figure to be between about 1.5 and 2.5 (cited in Coleman and Dye, 1996). Using these estimates of R_0 in the well-established formula (Anderson and May, 1991) to estimate the critical vaccination threshold (P_{crit}) required to prevent outbreaks of infectious diseases ($P_{crit}=1-1/R_0$), Coleman and Dye (1996) predicted that 70% vaccination coverage will reduce R_0 below the critical threshold of one (sufficient to prevent major outbreaks) approximately 95% of the time. This figure of 70% was in fact first recommended by the WHO as the critical percentage of dogs which needs to be vaccinated to prevent or control an outbreak of rabies, based on a consensus reached among veterinary practitioners in New York State in the 1940s – a neat example of the convergence of empirical and theoretical outcomes. In a more recent study, Hampson (2007) confirmed that R_0 for rabies was very low, both in her study areas in rural Tanzania (R_0 of ~1.2) and in a review of global canine rabies outbreaks (R_0 < 2). Following the method of Coleman and Dye (1996), she calculated the deterministic critical vaccination threshold for rabies control in rural Tanzania to be only 20%, rising to only 40% in areas where R_0 was found to be higher. As discussed above, relatively low levels of vaccination coverage (30-50%) have successfully controlled canine rabies in some circumstances, but higher levels have also failed. One possible reason for failure at higher levels is chance: small outbreaks occur by chance even when coverage exceeds

P_{crit}. Even at 70% coverage, there is still a 5% chance (based on the dataset of Coleman and Dye, 1996) that an outbreak will occur.

A more fundamental reason for the failure of rabies vaccination campaigns may lie in the fact that such campaigns are usually conducted in a 'pulse' fashion, typically annually or bi-annually, as opposed to the ongoing vaccination of susceptibles as they enter the population. Between campaigns, herd immunity may decline rapidly due to births (of susceptible dogs) and deaths (of vaccinated dogs). To prevent herd immunity falling below P_{crit} between campaigns, a larger proportion than P_{crit} of the dog population (P_{target}) must be vaccinated during the campaign: $P_{target} = e^{(v+d+r)T}P_{crit}$, where r is the rate of dog population growth, d is the death rate, $1/v$ is the duration of vaccine-induced immunity and T is the interval between campaigns (from Hampson, 2007). Estimates by that author of demographic parameters for domestic dogs in rural Tanzania suggest that annual campaigns should aim to vaccinate 60% of the dog population. These predictions are consistent with the results achieved by Cleaveland *et al.* (2003), discussed above.

In general, dog rabies vaccines have a high relative duration of protection, effective for up to three years in host populations whose average life expectancy is often shorter (cited in Coleman, 1999). However, an extension of life expectancy (particularly in populations in which recruitment remains high), perhaps through combined dog vaccination or health-care programmes which reduce mortality from causes such as canine distemper, parvovirus or helminthiasis, may reduce the impact of rabies vaccination. Further study into factors, anthropogenic or otherwise, regulating dog population growth and turnover will be necessary; what is currently obvious, however, is that aspects of host populations relating to vaccination coverage are not uniform across populations. Vaccine 'take' (the proportion of vaccinated hosts which actually become protected, as per Woolhouse *et al.*, 1997a) may also vary between programmes, although this is more likely due to factors affecting vaccine efficacy, such as the deficiencies in the cold-chain commonly encountered in the developing world. Differences in the genetic makeup of host populations in regions of the genome, such as the major histocompatibility complex (MHC) involved in the regulation of immune response (Kennedy *et al.*, 2002), may also influence host response to vaccination, and account for some variation in vaccine impact between populations.

Host population characteristics may also affect the outcomes of vaccination campaigns in other ways. The figure of 70% coverage assumes that all dogs within a population are equally exposed to infection, in other words that infected and susceptible individuals are perfectly mixed (Anderson and May, 1991). Although this is rarely the case in practice, little work has been done to assess the effects of heterogeneity within dog populations on the impact of rabies vaccination campaigns. Fully restricted dogs, such as those confined to a kennel or chained in a closed yard, do not mix freely with the remaining dog population and may be better considered a separate sub-population with little danger of infection, yet these are the animals easily accessible to vaccination. Conversely, feral and unrestricted dogs, who are most at risk of infection from other dogs within this category and from spill-over from wildlife reservoirs, are less likely to be vaccinated. Within these sub-populations age and sex differences in behaviour and home ranges, and clustering of dogs in high-density areas, may exacerbate inequalities in probability of exposure. The existence of any significant heterogeneities within given dog populations will require higher levels of overall vaccination coverage than those predicted by models working on an assumption of homogeneity (Anderson and May, 1991). It is also important under these conditions that vaccination be focused on the dogs most at risk of infection, a strategy which in some areas may necessitate the use of ancillary techniques such as oral vaccination or the promotion of good dog 'husbandry' practices to improve confinement. Identification of high-risk groups may allow for the specific targeting of vaccination effort (Woolhouse *et al.*, 1997b) which could potentially improve the cost-effectiveness of dog vaccination as a rabies control method even further.

Theory predicts a relationship between R_0 and population density (Coleman and Dye, 1996). Empirical evidence to support this relationship is however equivocal: although there is some evidence to support a threshold dog density necessary to allow rabies persistence in a population (Cleaveland and Dye, 1995), Coleman and Dye (1996) themselves found no effect of population density on R_0 (although their dataset was admittedly small). In a more recent analysis of a larger dataset, Hampson (2007) found no systematic differences in R_0 between outbreaks of rabies in dog populations from across the world. In addition, she was unable to detect differences in R_0 between their two study sites (two districts in northern Tanzania), despite substantial differences in dog population density. Her analysis of a detailed dataset of rabies transmission collected from these two sites concluded that stochasticity arising from individual variation in biting behaviour may mask any underlying variation in R_0 driven by population density.

The remarkably low and consistent estimates of R_0 for rabies by Hampson (2007) support the empirical observations that annual campaigns at which 70% coverage is achieved are effective for long-term control of canine rabies. Certainly, in the absence of detailed and costly dog demographic studies across the range of habitats occupied by this ubiquitous species, it seems prudent to maintain this target as a recommendation unless and until local data suggests otherwise.

1.7 Oral Vaccination of Dogs

Animal rabies vaccines can be categorised on the basis of the route of delivery (parenteral or oral) or the preparation of the antigenic component of the vaccine (inactivated virus, modified live virus or recombinant vaccines), and are reviewed by Dreesen (2007). First-generation rabies vaccines were produced using infected animal nerve tissue attenuated by desiccation and later phenol (Bunn, 1991). These nerve-tissue origin (NTO) vaccines are cheap to produce and are still used in mass dog vaccination campaigns in parts of Africa, Latin America and the Caribbean, where they are primarily produced from rabies-virus infected suckling mouse or lamb brains. However, NTO vaccines (for both human and animals) have the potential to cause severe neurological sequelae in vaccinees, and the search for safer options lead to the development of modified live virus (MLV) vaccines, in which strains of virus are adapted after serial passage to grow on chick embryo or tissue culture cells. These MLV vaccines are still used extensively in Asia, Africa and some parts of Europe, although the WHO no longer recommend MLV vaccines for parenteral use in animals (WHO, 2004) and MLVs are gradually being replaced by the use of inactivated cell culture vaccines. High concentrations of virus are grown on cell cultures such as baby hamster kidney or Vero cells, and then inactivated (killed) by various methods, the most common of which is the application of beta propiolactone. These vaccines have proven to be safe and effective, although somewhat more expensive than MLV or NTO vaccines. More recent innovations include the development of recombinant vaccines, in which a section of the rabies virus genome (typically the glycoprotein gene, which normally expresses the antigenic but non-pathogenic outer structural protein on the surface of the viral envelope) is inserted into the genome of a vector virus. Vectors used to date include the Copenhagen strain of vaccinia virus, canarypox virus and adenovirus.

Parenteral (strictly meaning administered by means other than through the alimentary tract) rabies vaccines are delivered by either intramuscular or subcutaneous injection. Inactivated NTO and cell culture vaccines, MLVs and some recombinant vaccines (canarypox- and adenovirus-vectored) are typically administered by this route. The first rabies vaccines to be successfully administered orally were MLV vaccines using the Street Alabama Dufferin (SAD) strain of virus. These oral rabies vaccines (ORVs) have been produced for use in baits for wildlife species that serve as reservoirs of the disease. The modified-live SAD vaccines, which were found to contain some residual pathogenicity for rodents, have largely been replaced by the SAG-1 and SAG-2 (SAD-

Avirulent-Gif) strains in the development of ORVs, with the latter being the strain of choice. The live vaccinia-rabies virus glycoprotein recombinant vaccine is also effective when delivered by an oral bait, and has been used in the USA for the control of rabies in various wildlife species, including raccoons, coyotes and gray foxes.

Since the successful eradication of sylvatic rabies in western Europe through the use of ORVs (Müller, 2000), attention has turned to the application of this technology to domestic dog populations, particularly those characterized by a high proportion of dogs inaccessible to traditional mass parenteral vaccination methods (WHO, 1998). Several candidate vaccines (either modified live or live recombinant) are available. These can then be used in combination with a bait matrix formulated to appeal to domestic dogs, and delivered to the target population using several possible strategies. Baits generally consist either of commercially-produced artificial polymers with an appropriate aroma and flavour, or of locally-available, 'home-made' substances such as chicken heads or minced meat. The appropriate bait for a given setting will depend on a number of factors, including its acceptability to the target dog population, the number of baits required, and the chosen delivery method. For example, researchers in Sri Lanka found that commercially-available baits were too hard and lost their aroma after a long period of storage. These problems were overcome by flavouring the bait with canned fish and leaving it at room temperature for a few hours before delivery (Harischandra, 2001). A major consideration in the formulation of baits for specific species (including domestic dogs) is the need to ensure that the size and consistency of the bait is such that the target animal will chew the bait and not swallow it whole, ensuring sufficient interaction time of the vaccine with the pharyngeal immune system (Wandeler, 1991).

Bait delivery methods themselves will vary according to the objectives of the oral vaccination programme and the ecology of the local dog population. Strategies that can be considered include the distribution of baits to dog owners at a central point, handout of baits to dogs encountered in the street by vaccination personnel, presentation of baits to owned dogs through household visits, or placement of baits at locations known to be visited by feral or poorly-restricted dogs. By delivering baits to dog owners at a central point in Tunisia, Ben Youssef *et al.* (1998) showed that 85-90% of owned dogs could potentially be vaccinated in such a way. In Sri Lanka, delivery of oral vaccines to unvaccinated dogs during house-to-house visits following a parenteral vaccination campaign increased vaccination coverage from 45-76% (Harischandra, 2001), while in South Africa, 68% of owned dogs at least partially consumed a bait after house-to-house delivery by the vaccination team (Bishop, 2001). In Turkey, 30% of a sample of free-roaming dogs was found to have ingested baits placed out overnight in selected sites in an urban area of Istanbul (WHO, 1998).

Oral vaccination, either alone or more likely in combination with parenteral vaccination, may thus allow for improvement in dog vaccination coverage or for the targeting of high-risk, inaccessible segments of the population; however, further field studies to evaluate economy, efficiency and effectiveness, and to demonstrate safety are required before this method can be recommended for broader application. A continuing obstacle to the widespread deployment of oral rabies vaccines for dogs is human health concerns. Although the danger posed to human health by either recombinant or modified live rabies vaccines is extremely slight (particularly when weighed against the threat of canine rabies in endemic areas), it is not negligible, given the extremely close association of dogs with human populations. In the developing world at least, the human population may contain a high number of immunosuppressed individuals. The potential advantages of oral rabies vaccines need to be weighed against the attendant risks by national authorities contemplating their use. It must be said, however, that in specific circumstances, such as in rabies-endemic areas with high dog densities and large numbers of feral or poorly-supervised animals, the benefits are likely to be substantial if appropriate strategies are used. Further research will hopefully allow these benefits to be realised safely and effectively.

1.8 Age at First Vaccination

Current vaccination practices exclude an important and easily accessible segment of the dog population from immunisation – puppies below the age of three months. This stems from vaccine manufacturers' recommendations that for dogs born of immunized bitches the minimum age of vaccination should be 3 months, so that vaccine-induced active immunity is not affected by the presence of maternally derived antibodies. Conflicting evidence for this position is to be found in the published literature. One laboratory study (Précausta *et al.*, 1985) indeed found that antibody production in puppies born to immunized bitches was inhibited by the persistence of maternal antibodies when the puppies were administered an inactivated rabies vaccine at one month. A further study however showed that, although vaccination with an inactivated vaccine of 14-day old puppies with high levels of maternal antibodies did not raise those animals' antibody titres, all puppies survived when challenged 6 months later with a dose of field rabies virus that killed all unvaccinated controls (Chappuis, 1998). A possible explanation could be that maternal antibodies do not appear to inhibit specific T-cell responses, even while completely impeding antibody production (Siegrist *et al.*, 1998). T-cells, thus primed, may offer protection through accelerated antibody response following subsequent exposure to antigen. In a field trial in Tunisia, Seghaier *et al.* (1999) found that puppies' serological response to rabies vaccination were similar, whether in the presence or absence of maternal antibodies. Taken together, these findings strongly suggest that vaccination of puppies as young as two weeks old will confer protection against rabies, whatever the pre-existing immune status of the animal.

Given that few adult dogs and fewer puppies have detectable antibody titres in many settings in the developing world anyway, and that young dogs are important sources of human rabies cases despite being easily accessible to vaccination (Mitmoonpitak *et al.*, 1998), vaccination of dogs younger than 3 months should no longer be precluded on the grounds of poor immune response. A valid consideration, and one whose effect may vary between populations, is the high mortality rate suffered by this segment of the population (up to 50%: Coleman, 1999), which would negatively impact the cost-effectiveness of any campaign that targeted it. Mitigating this is the 'pulse' nature of typical dog rabies vaccination campaigns, in which mass immunization of the host population is conducted over a short period of time at fixed (though often infrequent) intervals. Puppies considered too young for vaccination may be one or even two years old, and constitute up to a third of the population (Coleman, 1999), before a second opportunity for immunisation arises. A cost-effectiveness model incorporating age-specific mortality rates will be useful in assessing the optimal strategy.

1.9 Dog Rabies Control in Wildlife Conservation

Several approaches have been suggested as a means to minimise the threat of rabies to endangered wildlife (reviewed by Laurenson *et al.*, 1997b). The issue rose to prominence in the wake of a prolonged debate regarding the risk and benefits of directly vaccinating African wild dogs in the Serengeti-Mara ecosystem of Tanzania and Kenya against rabies in an attempt to prevent further outbreaks of disease. The debate focussed on a hypothesis that the stress of rabies vaccination was responsible for causing mortality, and ultimately, the local extinction of the wild dog population, through re-activation of 'latent' rabies infection (Burrows *et al.*, 1994, 1995). Although this hypothesis has been widely refuted (e.g. Macdonald *et al.*, 1992; Creel *et al.*, 1997; Woodroffe, 2001), the debate had widespread repercussions, with wildlife managers in many parts of the world reluctant to permit vaccination of wildlife. As a result, vaccination of domestic dog reservoirs has been adopted as the main approach for protecting endangered wildlife against rabies, with large-scale programmes implemented around the Serengeti National Park (to protect African wild dogs) and the Bale Mountains National Park (to protect Ethiopian wolves).

Population viability analyses indicate that for both Ethiopian wolves (Haydon *et al.*, 2002) and African wild dogs (Vial *et al*,. in press), it may be sufficient to vaccinate only a core of 20-40% of individuals, as the objective (from the conservation perspective) need not be the elimination of rabies, but rather the avoidance of the largest outbreaks that could result in extinction. Given the challenges of maintaining vaccination coverage in large and rapidly-growing domestic dog reservoir populations, a policy of core vaccination of target species may prove to be a more feasible and cost-effective approach for conservation management. For example, despite enormous efforts in Ethiopia to vaccinate domestic dogs surrounding wolf habitat in the Bale Mountains National Park, the incursion of a single rabid dog triggered a major new epidemic in wolves in 2003 (Randall *et al.*, 2004). Nonetheless, the added public health and economic benefits of dog vaccination to communities may justify a dual approach.

1.10 Economics Of Dog Vaccination For Rabies Control

The primary objective for controlling canine rabies is the elimination of disease in the human population. The disease can be completely eliminated in humans through two major approaches: i) greater availability of PEP, or ii) elimination of canine rabies by controlling the disease in the principal reservoir host. Economic studies indicate that controlling the disease in the canine reservoir is the most cost effective approach for preventing rabies in humans (Bögel and Meslin, 1990). Available country-level estimates on the macro-economic impact of rabies suggest that rabies impinges greatly on national economies and control of the disease should result in significant savings in national health budgets. In the Philippines, for example, it is estimated that rabies control would result in a net economic benefit of up to $2.5 million annually (Fishbein *et al.*, 1991). In Tanzania, a country which is reported to spend at least $400 000 of its health budget on PEP alone (Meslin, 1994), control of dog rabies could result in a net saving of up to $12 060 per 100 000 people per year (Kaare, unpublished data). In both cases, the saving represents a significant proportion of respective country health budgets. Further analyses of the economics of rabies control would benefit from detailed costings of dog rabies vaccination campaigns, for example as was done by Kayali *et al.* (2006) in Chad.

Rabies also affects individual household economies. A large proportion of the rural population in Africa and Asia subsists below the poverty line, yet it is in these rural areas that rabies has its most profound economic impact. Knobel *et al.* (2005) predict that five times more deaths due to rabies occur in rural areas than in urban areas (it is ironic, in fact, that the term 'urban rabies' is so often used synonymously with canine rabies). The greatest problem at the household level is the expense associated with PEP. The human rabies vaccine is not only expensive relative to rural household incomes but is also rarely available in the vicinity of most rural populations who, more often than not, are compelled to travel long distances to obtain PEP, paying for both travel and boarding costs. In Tanzania, studies indicate that only 33% of households with dog bite victims were able to meet the costs of PEP from their own family savings (Kaare, unpublished data). The remaining proportion had to raise funds from other means including borrowing money, selling household properties and livestock, and mortgaging land. The same experience has been noted in India, where a labourer was compelled to sell one third of his land to raise funds for his child's PEP (Dutta, 1996), although the child eventually died. Household economies are also affected through livestock losses. Household losses up to a mean of $7.5 per year have been reported in Ethiopia (Laurenson *et al*., 1997a), a considerable loss in a country where many households earn less than $1 a day. Although studies on livestock losses due to rabies are few, anecdotal evidence from some parts in north western Tanzania suggests that the problem is likely to be greater than originally thought.

The economic benefits of ensuring the survival of endangered wildlife populations through dog rabies control remain to be quantified. However, wild dogs are reported to be one of the major attractions for tourists visiting South African national parks (Lindsey *et al*. 2005) and, given the importance of wildlife tourism in the economies of many countries in sub-Saharan Africa, these impacts should not be ignored.

1.11 Dog Population Management

As mentioned previously, there is no evidence that removal of dogs alone has ever had a significant impact on dog population densities or the spread of rabies. However, dog population management through movement restriction, habitat control, reproductive control, and, in certain select circumstances, humane killing of dogs, may be used to supplement mass dog vaccination campaigns in national rabies control programmes.

This could be achieved through increased confinement of owned dogs to premises by either kennelling or collaring, securing potential food resources such as waste dumps, slaughter slabs or latrines against access by feral dogs, or by reducing the need for dogs through improvement in husbandry methods to protect livestock against predators. The importance of resource availability in rabies epidemiology is illustrated by the reported rise in dog rabies cases in the wake of the dramatic declines in vulture populations across the Indian sub-continent (Prakash *et al.*, 2003). One of the most notable effects of the absence of vultures was the accumulation of carcasses that permitted a 20-fold increase in domestic dog numbers (Pain *et al.*, 2003).

Reproductive sterilisation of dogs by castration, ovariohysterectomy or delivery of hormonal contraceptives has been proposed as means of reducing population turnover and (in combination with vaccination) creating a stable, immunised dog population. To prevent outbreaks of rabies, vaccination coverage - the number of vaccinated dogs V divided by the total population size N - must be maintained above P_{crit}. Following a single pulse vaccination campaign, the number of vaccinated dogs declines as individuals die and vaccine-induced immunity wanes ($V_t=V_0e^{-(d+v)t}$), while the total population continues to grow ($N_t=N_0e^{rt}$), where r is the rate of dog population growth, d is the death rate and $1/v$ is the duration of vaccine-induced immunity (Hampson, 2007). To assist rabies control efforts (by decreasing the proportion of animals that needs to be vaccinated during a campaign, P_{target}) animal birth control (ABC) programmes would need to decrease r by decreasing the per-capita birth rate, itself a product of the sex ratio, average litter size and frequency, and pup survival. Reproductive control of breeding females through ovariohysterectomy or hormonal contraception should achieve this by reducing the average number of litters, on the assumption that this does not lead to compensatory increases in pup survival or immigration of new, unvaccinated dogs into the area, or to increases in adult mortality. Such ABC programmes have been launched in a number of countries with reportedly encouraging reductions in unsupervised dog numbers, human bite injuries and rabies cases (WHO, 2004). However, independent evaluation of these projects in terms of impact and cost-effectiveness is needed before general recommendations on reproductive management as a rabies control method can be made. Ultimately, such cost-effectiveness assessments will need to evaluate mass dog vaccination campaigns at shorter intervals against the use of mass vaccination campaigns in combination with ABC programmes.

1.12 Conclusion

In this chapter, we have shown that the tools for dog rabies control, particularly those targeting vaccination of domestic dogs, are well developed and effective where they have been deployed appropriately. Successful dog rabies control programmes have had a substantial impact on human public health by reducing rabies-related mortality. The tools for canine rabies control are available. However, the neglected status of rabies and the lack of sufficient information on the public health burden of the disease result in its low prioritisation against competing health interests; for example, in the Global Burden of Disease studies undertaken by WHO and the World Bank (World Bank, 1993), rabies was not even mentioned, even though other disease problems such as dengue (Rigua-

Pérez *et al.*, 1998), which have a lower global disease burden, were well documented (Coleman *et al.*, 2004). At national levels, there is a lack of motivation, commitment and particularly resources, to gather data to promote a rabies control agenda. If rabies were to be better prioritised, efficient delivery systems, public education campaigns and resources to apply these technologies would soon follow. It is encouraging that, in an existing case study, the demand for PEP dropped significantly when rabies was well controlled in the dog population (Cleaveland *et al.*, 2003).

Canine rabies control must, however, be locally adapted and culturally sensitive. The relationship between humans and dogs, and the roles the animals play, differs between societies, and these differences will drastically impact on the acceptability of one or other control activity – e.g., dog accessibility and the choice of vaccination strategy. Similarly, dog ecology differs regionally; in some areas, dogs may roam over great distances, while in others, individual dogs may be more restricted with limited contact with other dogs. Rabies transmission between dogs and from dogs to humans is affected by these variations. A fuller understanding of dog ecology in different settings is thus required to optimise strategies targeting rabies transmission in canines.

Zoonotic disease control requires strengthening of partnerships in the medical and veterinary fields, both in the public and private sectors (King *et al.*, 2004). The nature of these partnerships might simply be in the exchange of information (occurrence of outbreaks, results of laboratory testing) or more formally arranged, such as in jointly managed – and funded – control projects. This would be the application of the "One

Medicine" concept (Schwabe, 1984), in which human and animal diseases are considered under a single paradigm. Rabies control focussing on the canine reservoir is an ideal example of where such veterinary and medical collaborations may have great benefits. Zinsstag *et al.* (2007) showed that mass vaccination of dogs is a comparatively cost-effective means of preventing human exposure and disease, particularly in resource-limited countries. Further, more detailed research into this topic is required, particularly incorporating dog population dynamics and the risk of rabies reintroduction from outside sources. Institutions in affected countries must widen their perspectives, and see beyond their specialised budgets; if both veterinary and medical budgets include rabies control, the winner in the end will be society as a whole, and the overall economic and disease burden in both humans and animals will be diminished.

One obstacle to improving the prioritisation of rabies control in health-care policy is a lack of information on the public health and economic burden of the disease, particularly in developing countries. The next chapter presents a first attempt to quantify this burden in Africa and Asia.

2 CHAPTER 2: RE-EVALUATING THE BURDEN OF RABIES IN AFRICA AND ASIA

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2.1 Introduction

More than 99% of all human rabies deaths occur in the developing world (World Health Organization, 1998), and although effective and economical control measures are available (Bögel & Meslin, 1990; Cleaveland *et al.*, 2003), rabies remains a neglected disease throughout most of these countries (Meslin *et al.*, 1994; Warrell & Warrell, 1995). A major factor in the low level of political commitment to rabies control is a lack of accurate data on the true public health impact of the disease. It is widely recognized that the number of deaths officially reported greatly underestimates the true incidence of disease. Patients may not present to medical facilities for treatment of clinical disease, few cases receive laboratory confirmation, and clinical cases are often not reported from local to central authorities (World Health Organization, 1998; Cleaveland *et al.*, 2002; Fekadu, 1997).

These problems are not unique to rabies and the recognized poor quality of much public health information from developing countries has prompted several recent investigations into the distribution of major infectious diseases and the mortality and morbidity attributable to them. Such studies are based on estimates of occurrence extrapolated from more readily quantifiable determinants of disease such as vector distribution or host immunity (Dye *et al.*, 1999; Snow *et al.*, 1999; Roth *et al.*, 2003). For rabies, a similar predictive approach has been used to estimate human rabies deaths in the United Republic of Tanzania, using a probability decision tree method to determine the likelihood of clinical rabies developing in a person following the bite of a suspect rabid dog (Cleaveland *et al.*, 2002). Dog-bite injuries are proportionately more frequently reported than human rabies cases and may provide an accessible data source from which human rabies deaths can be inferred. The objective of the current study was to estimate the burden of rabies in Africa and Asia by applying data derived from these regions to the model, and to thereby present a data-driven assessment of the human and economic costs of rabies in the developing world. In this report, 'Africa' is defined as all mainland countries on the continent plus Madagascar, whereas 'Asia' is those countries falling under the WHO-defined South-East Asia (SEARO) and Western Pacific (WPRO) regions, with the inclusion of Pakistan. Only countries considered by the World Health Organization and the *Office International des Epizooties* as having endemic canine rabies were considered in the analysis. The list of all countries included in the study is given in Appendix 1.

2.2 Methods

2.2.1 Human rabies deaths

Full details of the methodology employed in the dog-bite probability model are published elsewhere (Cleaveland *et al.*, 2002). Briefly, the model recognises that not all bites from rabid dogs result in infection, and that not every infection leads to clinical signs and death. One of the principal factors influencing the outcome of a bite from a rabid dog is the location of the bite on the body (Baltazard & Ghodssi, 1954; Shah & Jaswal, 1976). The model uses the distribution of injuries on the body, together with the likelihood of the patient receiving successful post-exposure treatment, to predict the outcomes of rabid dog bites. The model thus allows the incidence of suspect rabid dog bites among the at-risk human population to be used as a determinant of the number of human rabies deaths.

The human population at risk from canine rabies was taken as the number of people living in rabies-infected areas where the dog population density exceeds the threshold density at which canine rabies is capable of being maintained endemically. Dog population densities were inferred from human densities derived from two regional population density datasets (Deichmann, 1996a & b) with adjustments to account for population growth (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2003). Associated dog population numbers were calculated by dividing human figures by the regional average human:dog ratio, based on values given in Table 2.1. The threshold density for rabies persistence was taken as 4.5 dogs/km^2, based on model predictions produced from data on rabies transmission in rural Kenya (Kitala *et al.*, 2002), which are consistent with empirical observations from elsewhere in Africa (Foggin, 1988; Brooks, 1990; Bishop, 1995; Cleaveland & Dye, 1995). This density falls within the range of rural dog population density estimates (Childs *et al.*, 1998; Perry *et al.*, 1988; Pal, 2001), so the human population at risk was calculated using the regional rural human:dog ratios. Implicit in this approach is the assumption that all human urban populations are at risk in rabies-infected areas.

Four basic scenarios were considered (Africa and Asia urban/rural), as these reflect broad differences in factors that influence rabies epidemiology and the treatment of exposed persons. Initial parameter estimates were derived following a review of the relevant literature, including peer-reviewed journal publications, conference proceedings and other non-peer-reviewed sources. Parameter estimates and confidence distributions were then fixed using a three-stage consensus approach (Dye *et al.*, 1999) within the WHO Burden of Rabies Working Group: 1) a workshop was held during which parameter estimates were presented and discussed and preliminary predictions made with the model, 2) a comprehensive analysis using agreed- upon estimates was conducted and the model validated against known data, and 3) each participant was sent the results of this analysis, along with the data and assumptions. These were reviewed and adjusted as appropriate and final agreement reached. The final model parameter estimates and distributions are presented in Table 2.2.

Table 2.1. Mean human:dog ratios (95% confidence intervals) for Africa and Asia, determined from reference sources given in Appendix 2a. Insufficient data were available to calculate a separate figure for India, or for rural vs. urban China.

Africa		Asia		China
Urban	**Rural**	**Urban**	**Rural**	
21.2 (12.5 – 37.1)	7.4 (5.7 – 9.7)	7.5 (4.8 – 10.1)	14.3 (0 – 45.0)	48.3 (0 – 147.0)
12.3 (11.2 – 20.6)		9.5 (4.5 – 14.6)		

For the model analysis, Asia was subdivided into three units: India, China and Other Asia. Initial data sources and model validation indicated that parameter estimates for India and Other Asia are similar. However, preliminary model predictions for China overestimated the number of deaths by one order of magnitude when these same estimates were used, compared to the 1,000 deaths suggested by expert opinion. The discrepancy is possibly explained by the use of post-exposure treatment in China: the country is responsible for two-thirds (5 million cases) of the total PET use in Asia (World Health Organization, 1999), and the locally-produced tissue-culture vaccine is safe and relatively inexpensive (Lin & Lina, 2000). These factors suggest that post-exposure treatment for rabies is more accessible and utilised in China than in the rest of Asia. To account for this in the model, the probability of a person bitten by a suspect rabid dog receiving post-exposure treatment was assumed to be equally high in both urban and rural settings in China (min 95%, most likely 97%, max 100%). In light of the paucity of available data for China, the model predictions for this country should be treated with caution.

The model was arrayed as a spreadsheet template (Microsoft Excel 2000, Microsoft Inc, Redmond, Washington). Uncertainty in parameter estimates, and inherent parameter variability due to between-country differences, was incorporated into the model by

Table 2.2. Parameter estimates, probability distributions and data sources used in the prediction of human rabies deaths from dog bite injury data. Data sources are given in Appendix 2b.

Parameter	Description	Probability distribution	Parameter estimates: Africa Urban	Africa Rural	Asia Urban	Asia Rural	Source of data
	Annual incidence of suspect rabid dog bites per 100,000 humans	Trigen[a]:					1-6
		Practical minimum	6	6	50	15	
		Most likely	100	100	120	100	
		Practical maximum	227	227	250	250	
		Bottom & top percentiles	0%; 95%	0%; 95%	5%; 95%	5%; 95%	
P10	Probability of an individual bitten by a suspect rabid dog receiving successful post-exposure treatment	Trigen:					2, 7
		Practical minimum	0.80	0.55	0.95	0.70	
		Most likely	0.85	0.60	0.97	0.75	
		Practical maximum	0.90	0.60	1.00	0.80	
		Bottom & top percentiles	5%; 95%	5%; 95%	10%; 100%	10%; 90%	
P1	Probability of a suspect rabid dog being confirmed rabid on laboratory diagnosis	Beta[b]:			India	Other Asia	2, 3, 8-15
		No. of suspect dogs examined	9285		5863	59588	
		No. confirmed rabid	5291		2906	22923	
		P1	0.64		0.50	0.38	
P2	Probability of a bite injury to the head/neck	Point probability	0.07				2, 16, 17, E. Miranda (unpubl.)
P3	Probability of a bite injury to the upper extremity (arm/hand)	Point probability	0.38				2, 16, 17, E. Miranda (unpubl.)

Table 2.2 ***cont.***

Parameter	Description	Probability distribution	Parameter estimates	Source of data
P4	Probability of a bite injury to the trunk	Point probability	0.06	2, 16, 17, E. Miranda (unpubl.)
P5	Probability of a bite injury to the lower extremity (leg/foot)	Point probability	0.49	2, 16, 17, E. Miranda (unpubl.)
P6	Probability of developing rabies following a rabid bite to the head	Triangular: Minimum Most likely Maximum	 0.30 0.45 0.60	18-21
P7	Probability of developing rabies following a rabid bite to the upper extremity	Triangular: Minimum Most likely Maximum	 0.15 0.28 0.40	18-21
P8	Probability of developing rabies following a rabid bite to the trunk	Triangular: Minimum Most likely Maximum	 0 0.05 0.10	18-21
P9	Probability of developing rabies following a rabid bite to the lower extremity	Triangular: Minimum Most likely Maximum	 0 0.05 0.10	18-21

[a]The Trigen distribution avoids the use of absolute maxima and minima by allowing the specification of a likely range for the parameter, together with an estimation of the probability that the parameter will fall outside this range (top & bottom percentiles)..

[b]The Beta distribution is a binomial process allowing the estimation of the probability of success p, given s successes from n trials. Assuming a non-informative Uniform (0,1) prior, the Beta distribution takes the form p = Beta (s+1, n-s+1). See Vose (2000) for a discussion of commonly used probability distributions.

assigning confidence distributions to input parameters. Parameter distributions were sampled iteratively (until convergence at <1.5%) using a Monte Carlo simulation procedure (@Risk Pro 4.5, Palisade Corp., Newfield, New York). Model predictions are reported using the means of the resulting probability distributions, with the 5^{th} and 95^{th} percentiles (90% confidence limits) as the lower and upper bounds, respectively.

2.2.2 Disability-adjusted life year score

The disability-adjusted life year (DALY) score is a standardised, comparative measure of the burden of disease. The DALY score for a particular condition is a composite score of the years of life lost (YLL) due to premature mortality, and the years of life lived with a disability (YLD) caused by the condition (Murray, 1994). For the calculation of a DALY score for rabies the following components were considered: 1) a 'direct' DALY score derived from mortality due to the disease, and 2) an 'indirect' DALY score, taking into account morbidity and mortality following side-effects of nerve-tissue vaccines.

2.2.2.1 Direct DALY score

The output of the predictive model provided the estimated annual number of rabies deaths. Age- and sex-structures of rabies cases were obtained from seven reported studies (Belcher *et al.*, 1976; Fekadu, 1982; Ayalew, 1985; Lakhanpal & Sharma, 1985; Kureishi *et al.*, 1992; Singh *et al.*, 2001; Yimer *et al.*, 2002). All parameter estimates and data sources related to the calculation of the rabies DALY score are given in Table

2.3. Using these parameter estimates, a DALY score for rabies was determined using previously described methodologies (Murray, 1994; Mathers *et al.*, 2001). Parameter variability was again incorporated by assigning confidence distributions and run using simulation software as described above. The 5th and 95th percentiles were used as lower and upper bounds for the predicted scores.

2.2.2.2 Indirect DALY burden

Evidence suggests that non-rabies induced morbidity and mortality may constitute a sizeable proportion of the rabies burden in developing countries. Approximately one-third of all human rabies post-exposure treatments (PETs) are carried out using crude nerve-tissue vaccines (NTVs) ((World Health Organization, 2002), despite the occurrence of severe and sometimes fatal allergic encephalomyelitic reactions (Held & Adaros, 1972; Swaddiwuthipong *et al.*, 1988; Bahri *et al.*, 1996). The NTVs were classified into two groups, based on differing incidence rates and clinicopathological signs of adverse reactions (Held & Adaros, 1972; Swaddiwuthipong *et al.*, 1988): 'Semple' type (made from phenol-treated sheep or goat brain tissue) and suckling-mouse brain derived vaccines. For the purpose of this preliminary analysis, disability weights for post-vaccinal neurological reactions, used in the calculation of the YLDs, were taken as those weights reported for similar conditions by Murray and Lopez (1996) (Table 2.3). The use of equivalent disability weights represents an admittedly crude first attempt to determine a YLD component of the DALY score for rabies; future attempts would benefit from a formal disability weighting procedure.

Table 2.3. Parameter estimates and data sources used in the calculation of the rabies DALY score. Data sources are given in Appendix 2b.

Parameter	Estimate		Source
	Africa	Asia	
Human rabies deaths per year	23,788 (7,280 – 44,112)	30,942 (6,017 – 61,657)	Model output (Table 3)
Post-exposure treatment cases per year	200,000	7,500,000	12-14, 23-27
Number of PET patients receiving nerve-tissue vaccines (%)	20,000 (10%)	2,475,000 (33%)	12-14, 23-27
Number of NTV patients receiving Semple-type vaccines (%)	16,000 (80%)	1,980,000 (80%)	12-14, 23-27
Number of NTV patients receiving suckling-mouse brain vaccines (%)	4,000 (20%)	495,000 (20%)	12-14, 23-27
Rate of neurological complications per 100 Semple vaccinees	Triangular: Min: 0.035 Most likely: 0.40 Max: 0.83		16, 28-31
Case-fatality rate for cases of Semple neurological complications	0.17		30, 32, 33
Disability weight for Semple neurological complications	0.613		Disability weight for bacterial meningitis – 34
Disability duration for Semple neurological complications	Triangular: Min: 1 day Most likely: 8 days Max: 1 year		35
Rate of neurological complications per 100 SMB vaccinees	Triangular: Min: 0.013 Most likely: 0.03 Max: 0.08		29, 31, 35, 36
Case-fatality rate for cases of SMB neurological complications	0.22		29
Disability weight for SMB neurological complications	0.725		Disability weight for an injured spinal cord – 34
Disability duration for SMB neurological complications	200 days		37
DALY formula parameters			
Discount rate r	0.03		38
Age-weighting correction constant C	0.1658		38
Age-weighting function constant β	0.04		38

2.2.3 The economic burden of rabies

The mortality rate and DALY score provide estimates of the burden of disease on human health. A second component of the impact of disease is the economic cost incurred by society as a result of the disease. The costs due to rabies were considered under the following categories: 1) direct (medical) human PET costs, 2) indirect (patient) PET costs, 3) dog rabies control costs, 4) livestock losses, and 5) surveillance costs. Tables 2.4 and 2.5 give a breakdown of the costing data used in the economic analysis.

For this analysis, direct medical costs included the cost of biologicals (rabies vaccines & immunoglobulin) and the cost of their administration, including materials and staff salaries. Indirect costs included out-of-pocket patient expenses such as transport costs to and from rabies-treatment centres, and patient income loss while receiving PET (Meltzer & Rupprecht, 1998). Costs associated with the treatment of dog bite wounds and the administration of antibiotics and tetanus immunizations were not included. Due to the erratic frequency of reporting, national numbers of PET patients treated annually were averaged over a period of five years (1996-2000). Countries for which no reports during the five-year period could be uncovered were considered not to have treated any patients. Post-exposure treatments were categorized by administration route (intramuscular or intradermal), on the basis that intradermal vaccination reduces costs by 60-80% compared to the standard intramuscular regimen (Pradhan *et al.*, 2001; Kamoltham *et al.*, 2002). Using national estimates of the proportion of PET patients vaccinated with each schedule, and adjusting to account for patient drop-out during the

Table 2.4. Direct (medical) post-exposure treatment costing data and sources (listed in Appendix 2b).

Parameter	Estimate: Africa	Estimate: Asia	Source
1. Patient numbers			
Post-exposure treatment cases per year	200,000	7,500,000	11-14, 23-27
Number of PET patients receiving tissue-culture vaccines (%)	180,000 (90%)	5,025,000 (67%)	11-14, 23-27
No. of TCV patients vaccinated intramuscularly (%)	180,000 (100%)	4,874,250 (97%)	11-14, 23-27
No. of TCV patients vaccinated intradermally (%)	0 (0%)	150,750 (3%)	11-14, 23-27
Number of PET patients receiving nerve-tissue vaccines (%)	20,000 (10%)	2,475,000 (33%)	11-14, 23-27
Number of PET patients receiving rabies immunoglobulin (RIG)	2,000 (1%)	450,000 (6%)	11-14, 23-27
Human RIG	0 (0%)	45,000 (10)%	
Equine RIG	2,000 (100%)	405,000 (90%)	
2. Costs			
a. Common costs			
Material costs per injection (includes needles, syringes, swabs etc)	US$ 0.10		E .Miranda (unpubl.)
Overhead costs per PET visit (includes anti-rabies clinic staff salaries and administration costs)	US$ 0.50		39
b. TCV costs			
i. Intramuscular vaccination			
Vaccine cost per dose	US$ 10.00		WHO Procurement Services, Geneva, July 2003
Visits per patient	3		40
Injections per patient	3		Assume standard Essen regimen
ii. Intradermal vaccination			
Vaccine cost per dose	US$ 2.50		WHO Procurement Services, Geneva, July 2003
Visits per patient	3		E .Miranda (unpubl.)
Injections per patient	6		Assume Thai Red Cross regimen
c. NTV costs			
Vaccine cost per dose	0.4		7
Visits per patient	7		33
Injections per patient	7		Assume standard regimen
d. RIG costs			
Human RIG cost per dose	US$ 110.00		WHO Procurement Services, Geneva, July 2003
Equine RIG cost per dose	US$ 25.00		WHO Procurement Services, Geneva, July 2003

Table 2.5. Indirect (patient) PET costs and other costs associated with rabies. Data sources are listed in Appendix 2b.

Parameter	Estimate		Source
	Africa	Asia	
1. Indirect PET costs			
Number of PET patient visits	680,000	32,400,000	Calculated from Table 4a
Proportion of visits accompanied by an adult	0.4	0.4	2, 16
Total no. of visits (patients + accompanying persons)	952,000	45,360,000	Calculated
a. Income loss			
No. of working days lost per person per PET visit	0.5	0.5	15
Daily per capita Gross National Income (GNI)	US$ 1.87	US$ 3.50	41
Income loss per person per PET visit	US$ 0.94	US$ 1.75	Calculated
b. Transport costs			
Transport costs per person per visit	US$ 2.00	US$ 3.80	40, M. Kaare (pers. comm.)
2. Dog rabies costs			
a. Vaccination costs			
Number of dogs vaccinated annually	6,700,000	40,000,000	11-14, 23-27
Cost per dog vaccinated	US$ 1.30	US$ 1.30	42
b. Population control costs			
Number of dogs killed annually	200,000	5,000,000	11-14, 23-27
Cost per dog killed	US$ 5.00	US$ 5.00	43
3. Livestock losses			
Total number of cattle	230,000,000	423,000,000	44
Rabies incidence rate/100,000 cattle	5	5	11-14, 23-27
Annual number of cattle rabies deaths	11,500	21,150	calculated
Cost per head of cattle	US$ 150.00	US$ 500.00	A. Shaw (unpubl.)
4. Surveillance costs			
Number of rabies diagnostic tests per year	5,300	16,500	11-14, 23-27
Cost per test	US$ 5.68	US$ 5.68	45

treatment course, the total number of vaccine doses (i.e.injections) administered, and the total number of patient visits made to rabies-treatment centres, were derived. Few published accounts dealing with patient treatment-seeking behaviour and compliance could be found, so conservative estimates were made on the average number of visits per schedule: 3 instead of 5 for the Essen and Thai Red Cross, and 7 instead of 10-21 for the NTV schedules. The proportion of patients receiving the Zagreb schedule, based on available data, was negligible at the scale of the study. It was assumed that all children under the age of 16 were accompanied on their visits by an adult. Assessment of transport costs and income loss include both patient and accompanying person costs.

Annual dog vaccination figures could not be found for all countries, so the average vaccination coverage of the estimated national dog population was calculated for those countries submitting reports between 1996 and 2000 (10.3% in Africa and 9.7% in Asia) – this figure was then applied to all countries in the region to obtain a prediction of the total number of dogs vaccinated. Cost predictions were based on the use of a central-point vaccination system. Vaccination costs per dog include all components of campaign organization, public awareness efforts, biological and material costs. Indirect costs borne by dog owners were not included in the analysis.

Livestock losses to rabies can be significant; however, few published estimates of rabies incidence in livestock exist. Data based submission of cattle specimens to central veterinary laboratories reveal an annual incidence rate of between 0.5 - 2 deaths/100,000 head of cattle; this is certain to be a gross underestimate of the true number of deaths.

Assuming a rate of underreporting of 10x, and using the lower end of the range of incidence rates to exclude transmission from wildlife reservoirs, an estimated incidence rate of 5 deaths/100,000 cattle is obtained.

Insufficient data were available to enable parameter variability to be explicitly incorporated into the economic analysis. An attempt was made to model the uncertainty surrounding parameter estimates by inputting estimates as Triangular distributions (Vose, 2000), with the maxima and minima set as ± 10% of the parameters' values.

2.3 Results

2.3.1 Model outputs

The results of the predicted human mortality are presented in Figure 2.1 and Table 2.6, disability-adjusted life year score in Figure 2.2 and Table 2.7, and economic burden of rabies in Table 2.8. Figure 2.3 shows the results of the regression sensitivity analysis for the predicted human mortality. The predicted number of human deaths remained within the reported confidence bounds when the threshold dog density was doubled to 9 dogs/km^2 [46,000 (19,000 - 79,000)]. Setting the threshold density to 0 (i.e. assuming all people within endemic canine rabies areas to be at risk) also had little effect on the model: 67,000 (30,000 – 110,000) deaths are predicted in such a scenario.

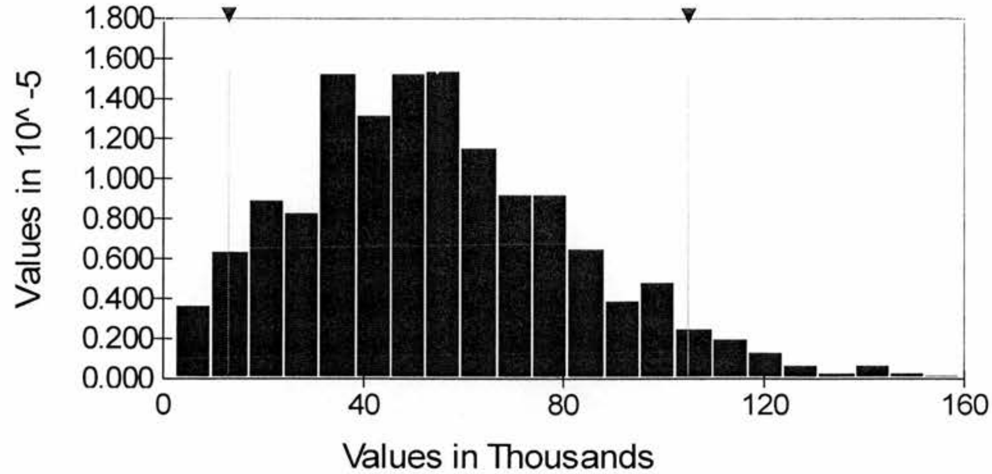

Figure 2.1. Frequency distribution of possible annual numbers of human deaths due to rabies in Africa and Asia, predicted by the model

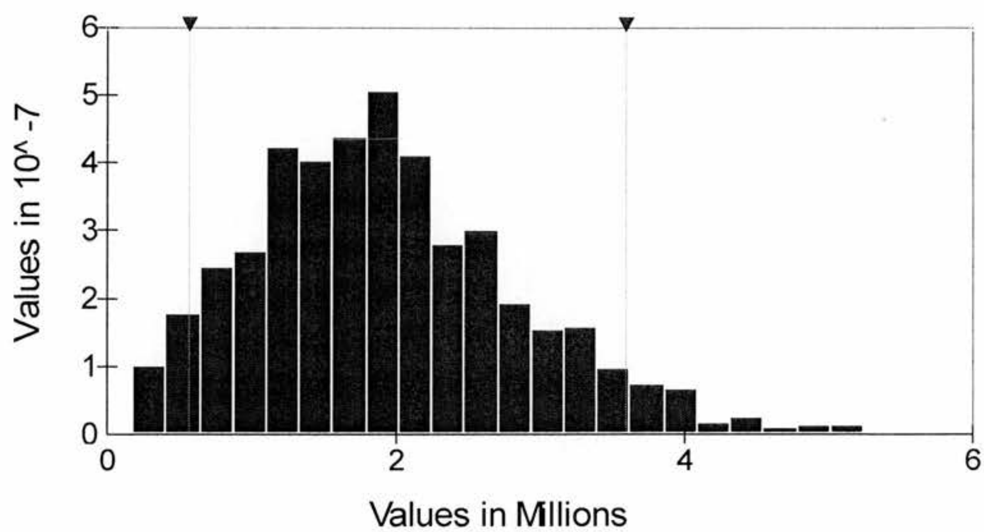

Figure 2.2. Frequency distribution of possible values of disability-adjusted life years lost due to rabies in Africa and Asia, predicted by the model

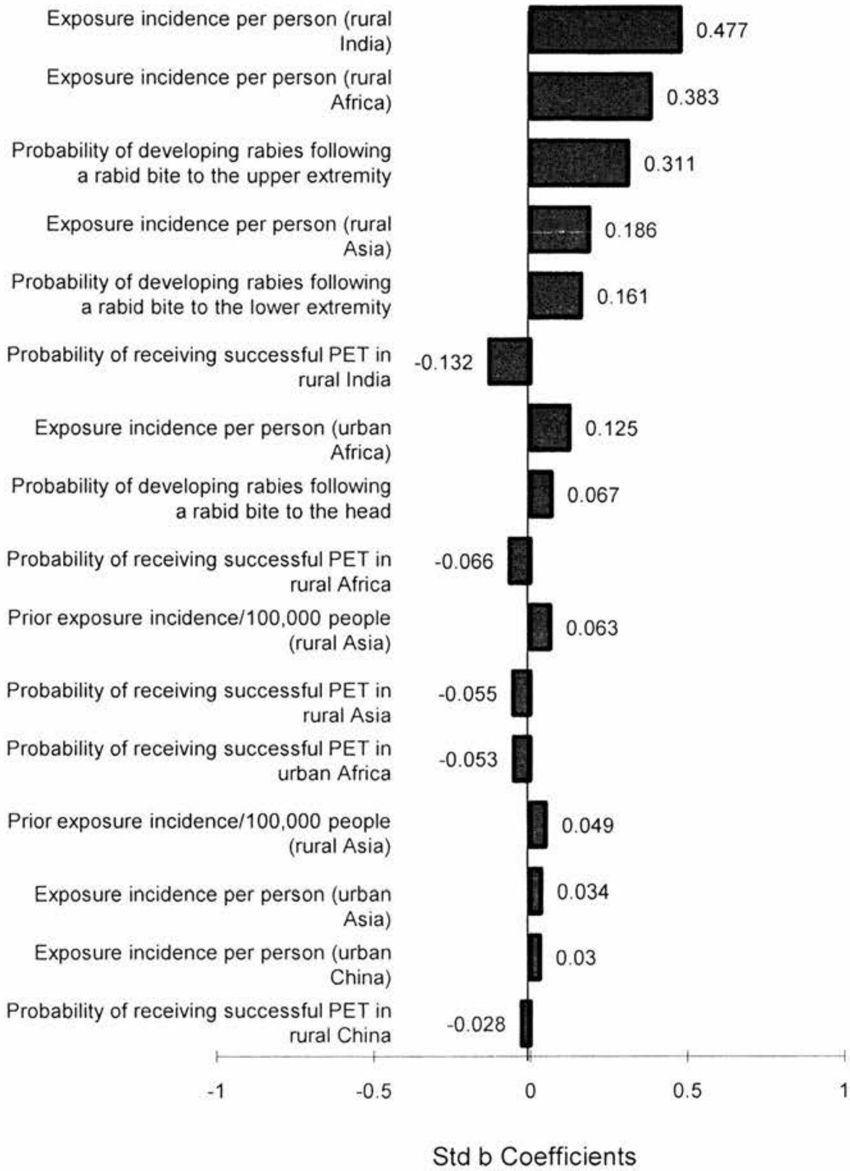

Figure 2.3. Regression sensitivity for the total number of human rabies deaths (with post-exposure treatment). Figures represent the change in output standard deviations given an increase of one standard deviation in the listed input variable.

Table 2.6. Estimated mortality due to canine rabies in Africa and Asia. Figures in parentheses are the 5th and 95th percentiles of output probability distributions.

Model output	Asia						Africa	
	India		China		Other Asia			
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Total population (millions)	284.7	732.2	459.1	816.1	295.7	525.4	294.2	498.1
Population at risk (millions)	284.7	710.4	459.1	498.3	295.7	409.1	294.2	340.1
Suspect rabid dog bites (thousands)	409.4	893.4	660.1	626.7	425.2	514.5	374.3	427.8
No. of rabies deaths*	1,058	18,201	1,324	1,257	853	8,135	5,886	17,937
Incidence/100,000	0.37	2.49	0.29	0.15	0.29	1.55	2.00	3.60
Sub-regional deaths	19,713 (4,192 – 39,733)		2,336 (565 – 5,049)		9,489 (2,281 – 19,503)			
Regional deaths			31,539 (8,149 – 61,425)				23,705 (6,903 – 45,932)	
Total deaths					**55,270** **(23,910 – 93,057)**			
Overall incidence/100,000					1.38 (0.60 – 2.33)			
Predicted deaths in the absence of any PET					327,160 (166,904 – 525,427)			

*Rabies deaths are the means of output probability distributions calculated independently and may therefore not sum exactly.

Table 2.7. Estimated DALY score for rabies in Africa and Asia

Component	DALY score Africa	Asia	Total
Rabies deaths	747,558 (217,690 – 1,448,514)	994,607 (257,275 – 1,939,125)	1,743,015 (754,019 – 2,934,656)
Nerve-tissue vaccine reactions	360 (142 - 586)	44,525 (17,585 – 72,575)	44,885 (17,727 – 73,162)
Total	747,918 (217,954 – 1,449,014)	1,039,119 (302,324 – 1,983,646)	**1,787,886** **(799,615 – 2,984,109)**
Total (assuming no PET)			9,504,237 (4,848,684 – 15,264,050)

Table 2.8. Estimated annual expenditure due to rabies (in millions of US$)

Category	Cost (in US$) Africa	Asia	Total
1. PET costs:	9.1 (8.2 – 10.0)	475.9 (435.0 – 520.5)	485.0 (443.4 – 530.1)
a. Direct (medical)	5.9 (5.2 – 6.6)	190.3 (171.4 – 210.5)	196.2 (176.9 – 216.7)
b. Indirect (patient)	3.2 (2.9 – 3.5)	285.6 (259.2 – 312.1)	288.7 (262.2 – 315.4)
Income loss	*1.3 (1.2 – 1.4)*	*113.5 (104.4 – 122.9)*	*114.7 (105.7 – 124.1)*
Transport costs	*1.9 (1.7 – 2.1)*	*172.1 (154.1 – 190.5)*	*174.0 (155.9 – 192.5)*
2. Dog rabies control costs	9.7 (8.8 – 10.6)	77.0 (71.5 – 82.3)	86.7 (80.7 – 92.8)
a. Vaccination costs	8.7 (7.8 – 9.6)	52.0 (47.1 – 57.0)	60.7 (55.4 – 66.3)
b. Population control costs	1.0 (0.9 – 1.1)	25.0 (22.5 – 27.5)	26.0 (23.4 – 28.6)
Livestock losses	1.7 (1.5 – 1.9)	10.5 (9.4 – 11.8)	12.3 (11.0 – 13.7)
Surveillance costs	0.03 (0.026–0.032)	0.09 (0.08 – 0.10)	0.12 (0.11 – 0.13)
Total cost	**20.5 (19.3 – 21.8)**	**563.0 (520.0 – 605.8)**	**583.5 (540.1 – 626.3)**

Table 2.9. The global DALY score for rabies and other selected infectious diseases[a]

Disease	**Total DALYs lost (x 1,000)**
Lymphatic filariasis	5,777
Leishmaniasis	2,090
Rabies	1,788
Schistosomiasis	1,702
Trypanosomiasis	1,525
Japanese encephalitis	709
Chagas disease	667
Dengue	616
Onchocerciasis	484
Leprosy	199

[a]Estimates for diseases other than rabies are revised Global Burden of Disease 2002 estimates, available from http://www.who.int/healthinfo/bodgbd2002revised/en/index.html and accessed on 18/10/2008

2.4 Discussion

As with any model, the outputs of the models presented here are only as good as the entered data. A major shortcoming is the lack of available data to allow the full variation in parameter estimates to be captured, particularly in the economic model (hence the rather crude use of equilibrium triangular distributions in an attempt to incorporate this). Further refinements of the probability estimates for the development of rabies following a rabid bite and in the absence of post-exposure treatment will not be possible, due to the obvious ethical implications. The model is sensitive to the estimates of these probabilities following a bite to the extremities (Figure 2.3), as these are the most common bite sites. The other variables to which the mortality model is sensitive, namely the exposure incidence per person in various settings, are more amenable to further quantification and the incorporation of these into future refinements of the model (at local, national or larger scales) is encouraged. One strength of the model, the preservation of which was sought in its presentation both in this volume and in Knobel *et al*. (2005), is its transparency – a full spreadsheet array of the model is available as an online appendix in the latter publication. It is hoped that this will allow future users to input locally-available data for applications at different scales (e.g. on local or national levels), or to refine parameter estimates and distributions at the current scale as further data become available.

This report provides the first attempt at a quantitative prediction of the burden of rabies in Africa and Asia. Although it was attempted to incorporate the entire range of parameter variability, the final result is still likely to be an underestimate of the total mortality and morbidity caused by rabies in these regions. Only deaths due to canine rabies were assessed, omitting that fraction of human cases resulting from exposure to rabid wild animals (World Health Organization, 2002). In determining the number of humans at risk, only populations in endemic canine rabies areas were included. This ignores the possibility of sporadic outbreaks in low dog-density zones or the introduction of the virus into a previously rabies-free population, as happened on the Indonesian island of Flores in 1997 (Bingham, 2001).

The results of the model are consistent with those of other studies that have estimated the true incidence of rabies at a national level. The recent national survey by the Association for the Prevention and Control of Rabies in India (2003) estimated a total of 18,500 human rabies deaths in the country each year, very close to the predicted figure of 19,700 in this report. The model also estimated the annual number of patients receiving PET in India as 1.07 million, again in good agreement with the reported national estimate of 1.1 million (Ichhpujani *et al.*, 2001). Model predictions for China are less consistent: the predicted number of PET patients of 1.25 million is four times lower than national estimates of 5 million, while the predicted number of deaths remains more than double that estimated by expert opinion. However, recent figures communicated by the Chinese authorities are more in line with model predictions (Francois Xavier-Meslin, WHO, personal communication, 2005): more than 2000 human rabies cases were reported in 2003, with an 80% increase in the first quarter of 2004 (compared to the same period in 2003). Given the gross underreporting associated with rabies deaths, this suggests that the model may in fact be an underestimate of the true number, and the original prediction of approximately 10,000 deaths may prove more realistic. Detailed studies on dog ecology and rabies epidemiology and treatment in China are necessary to resolve this.

Table 2.9 presents the estimated DALY figure for rabies in African and Asia (estimated in this study) together with the global DALY estimates for several other tropical infectious diseases, as estimated by the 2002 Global Burden of Disease study. As can be seen from the table, the rabies DALY burden is equivalent to that for Japanese encephalitis, dengue and onchocerciasis together.

The 1999 World Survey of Rabies (World Health Organization, 2002) reported 1,722 human rabies deaths from the study regions, 147 in Africa and 1,575 in Asia. The predicted figure of 55,000 deaths suggests that only 3% of human rabies deaths are recorded by central health authorities, a rate of underreporting of between 20 (Asia) and 160 (Africa) times. This is in agreement with findings of other studies using active surveillance methods, which indicate that the incidence of human rabies is up to 100 times greater than that officially recorded (Kitala *et al.*, 2000; Cleaveland *et al.*, 2002).

The burden of rabies is not evenly distributed across all sectors of society, but is influenced by age-related and socio-economic factors. The total cost (direct medical and indirect patient costs, excluding those of any accompanying persons) of an average post-exposure treatment course as determined in this study is \$39.57 in Africa and \$49.41 in

Asia. This amounts to a substantial fraction of the annual *per capita* gross national income (GNI): 5.80% for an average African citizen, and 3.87% for an Asian. Even if medical costs are fully subsidized by the government, out-of-pocket patient expenses still comprise 1.5% to 2% of *per capita* GNI. Often government subsidies extend only to the provision of cheaper nerve-tissue vaccines, with tissue-culture vaccines being provided only to those patients able to pay for them. There is therefore an income-related risk factor in exposure to the side-effects of nerve-tissue vaccines. This is compounded by occupational and socio-economic risk factors in initial exposure to infection, further skewing the burden of rabies towards those sectors of society least able to bear it (Tang *et al.*, 1997; Association for the Prevention and Control of Rabies in India, 2003) . The results of our study predict five times as many rabies deaths in rural than urban areas. Children in particular are at higher risk of exposure to rabid dogs. Typically, 30-50% of PET cases are children under 16 years of age (Dutta, 1999; Cleaveland *et al.*, 2002). Children are also more likely to suffer multiple bite injuries and bites to the face and head, both of which categories carry a higher risk of rabies developing (Kureishi *et al.*, 1992; Pancharoen *et al.*, 2001).

Rabies continues to impact human health, despite the existence of proven cost-effective control measures. Vaccination of the domestic dog population against rabies results in a significant reduction in the incidence of suspect rabid dog bites among the associated human population, and this control strategy has been shown to be the most cost-effective in the medium- to long-term (Meslin *et al.*, 1994), with costs typically recouped within 5 – 10 years, mainly through decreased expenditure on human post-exposure treatment.

Effective implementation of mass dog vaccination campaigns against rabies in developing countries will benefit from an improved understanding of the human-dog relationship in these regions. The following four chapters examine the factors associated with dog ownership and welfare in Tanzania (Chapter 3) and Sri Lanka (Chapter 5), and attempt to quantify and explore the attitudes of people in these areas which may underlie this relationship (Chapters 4 and 6).

3 CHAPTER 3: A CROSS-SECTIONAL STUDY OF FACTORS ASSOCIATED WITH DOG OWNERSHIP IN TANZANIA

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3.1 Introduction

Domestic dogs are ubiquitously associated with human populations in nearly all parts of the world. Reasons for keeping or tolerating dogs vary across societies and may involve aspects of security, companionship, transport, food acquisition or religious beliefs (Hart, 1995). Whilst broad cultural patterns in human-dog relationships can be defined (Brown, 1985; Davey *et al.*, 1998; Serpell, 2004), within these trends there remains considerable variation between individual social units (e.g. families or households) in attitudes towards and associations with dogs (Kidd & Kidd, 1989; Schenk *et al.*, 1994; Hsu *et al.*, 2003; Westgarth *et al.*, 2007). Understanding the demographics and predictors of dog ownership at a household level may be of importance in fields such as public health (Macpherson *et al.*, 2000; Kitala *et al.*, 2001; Robinson & Pugh, 2002) or social psychology (Garrity *et al.*, 1989; Serpell 1991; Raina, *et al.*, 1999; Hart, 2000; McNicholas & Collis, 2000), or of commercial interest in the provision and marketing of veterinary services and products (Wise *et al.*, 2003).

Although many societies derive benefits from their associations with dogs, dogs may also pose significant risks to human health and well-being (Weiss *et al.*, 1998; Talan *et al.*, 1999; Wandeler & Bingham, 2000). Of these, the transmission of rabies virus undoubtedly carries the most severe consequences. Dogs are the most important reservoirs of rabies virus in many parts of the world, particularly in developing regions such as sub-Saharan Africa, the Indian subcontinent and south-east Asia (Knobel *et al.*, 2007), and the vast majority of human rabies fatalities (typically >90%) in these regions are as a consequence of exposure to rabid dogs (World Health Organization, 1999). It is estimated that canine rabies kills over 55,000 people each year in Africa and parts of Asia alone (Knobel *et al.*, 2005). In addition to human deaths, canine rabies also imposes an economic burden on societies and individuals, in the form of costly post-exposure vaccinations required to prevent the development of clinical rabies following exposure to a suspected rabid animal (Knobel *et al.*, 2005). The burden of canine rabies often falls disproportionately on those least able to bear it: public health departments in developing countries already faced with controlling burgeoning rates of tuberculosis, malaria and HIV; low-income rural households from which patients may need to travel long distances to seek treatment; and children, who face a higher risk of rabies exposure and death (Knobel *et al.*, 2005).

In areas where canine rabies is endemic, epidemiological theory and economic analysis suggest that control efforts must focus on establishing and maintaining a high (>70%) vaccination coverage in the dog population (Bögel & Meslin, 1990; Coleman & Dye, 1996). Understanding the factors that affect the accessibility of dogs for vaccination is thus critical to local and national rabies control programmes. In sub-Saharan Africa, the results of several recent studies suggest that the proportion of unowned, feral dogs is low: the majority of dogs are accessible for vaccination through households which claim responsibility for them [26,27] (Kayali *et al.*, 2003; Gsell, 2006). Given this, a deeper understanding of the household-level factors associated with dog ownership in these communities may be important for public health planning of rabies awareness programmes and dog vaccination campaigns. While a number of studies have explored the factors associated with dog ownership among communities in developed countries [8,28-31] (Westgarth *et al*., 2007; Franti & Kraus, 1974; Franti *et al*., 1980; Teclaw *et al*., 1992; Leslie *et al*., 1994), few equivalent studies have been undertaken in developing economies. This paper reports the results of a large-scale cross-sectional study of dog ownership patterns across 12 study sites, encompassing both urban and rural agro-pastoralist households in central and eastern Tanzania.

3.2 Methods

3.2.1 Study design

Study sites were selected from each of three coastal (Dar es Salaam, Tanga and Pwani) and three inland regions (Kilimanjaro, Dodoma and Morogoro) in the United Republic of Tanzania (Figure 3.1). Within each region, the district containing the regional capital or major coastal city was selected, and from these a single urban ward was randomly selected. If the selected district contained a mix of urban and rural wards, then a single rural ward was also selected at random from the same district. If however the selected district was largely urban, then a rural ward was randomly selected from an adjacent rural district. Within selected wards, study site sizes were standardized such that urban sites contained 1,000-2,000 households, and rural sites 500-1,000. If the selected ward was too large, an appropriate number of contiguous administrative units (sub-wards) were selected as the study site. In this way, three study sites were selected in each of the four possible combinations of urban/rural and inland/coastal categories. These categories were chosen as they were believed to reflect hypothesised differences in socio-cultural aspects of dog ownership, such as the economic status and religious beliefs of households.

Within each study site, a dog rabies vaccination campaign was organised as part of a larger research project. Prior to the vaccination campaign, a simple random sample of households within a study site was selected for the cross-sectional survey. The working definition of a "household" was derived from the 2002 Tanzania Population and Housing Census (National Bureau of Statistics, 2004). If a sampling frame of all households was available from administrative authorities, a random-number generator was used to obtain a sample of 10% of the households, identified by the name of chief occupant. If no sampling frame was available, interviewers visited all households in the study area and determined if an interview should be conducted by blindly selecting coloured markers (one red and nine black). If the red marker was drawn the household was selected for an interview. If no adult ($\geq$ 16 years) was present, or if occupants declined to be interviewed, the next household (on the sampling frame list where applicable; physically adjacent where not) was selected; however, very few households were excluded in this fashion (<5%). A standardised questionnaire was administered to the most senior adult occupant of the household present, by one of four trained interviewers. Individual-level factors such as sex, age, level of education, occupation and religion were recorded for the head of the household. An asset approach was used as a measure of socio-economic status (Gwatkin *et al.*, 2000): the questionnaire included details of the construction material of the housing unit, ownership of certain consumer items (working radio, television, refrigerator, bicycle, motorcycle, car) and availability of utilities such as electricity and piped water. Principal components analysis was used to assign a weight to each household asset and the resulting asset scores were standardized in relation to a normal distribution with a mean of zero and a standard deviation of one (Filmer & Pritchett, 2001). Standardized scores were summed for each households, and households classified according to asset quintile, with 1 = poorest and 5 = least poor.

3.2.2 Model building

Households were classified as dog-owning (DOHH) or non-dog-owning (NOHH). The occupations of the heads of the household were initially classified into one of 13 categories, based on the major groups identified in the Revised International Standard Classification of Occupation (International Labour Organisation, 1990), with some additions. This includes a category of 'Elementary occupations' (category 9, including for example domestic helpers and farm labourers, with designated ISCO skill level 1). Subsequently, non-elementary categories (e.g. trade workers, professionals and associate professionals, with ISCO skill levels 2-4) were combined into a single category ('Secondary' occupations). Unemployed persons were classified within 'Elementary' occupations as many people not in formal employment still engage in subsistence farming (considered by the ILO as an 'Elementary' occupation).

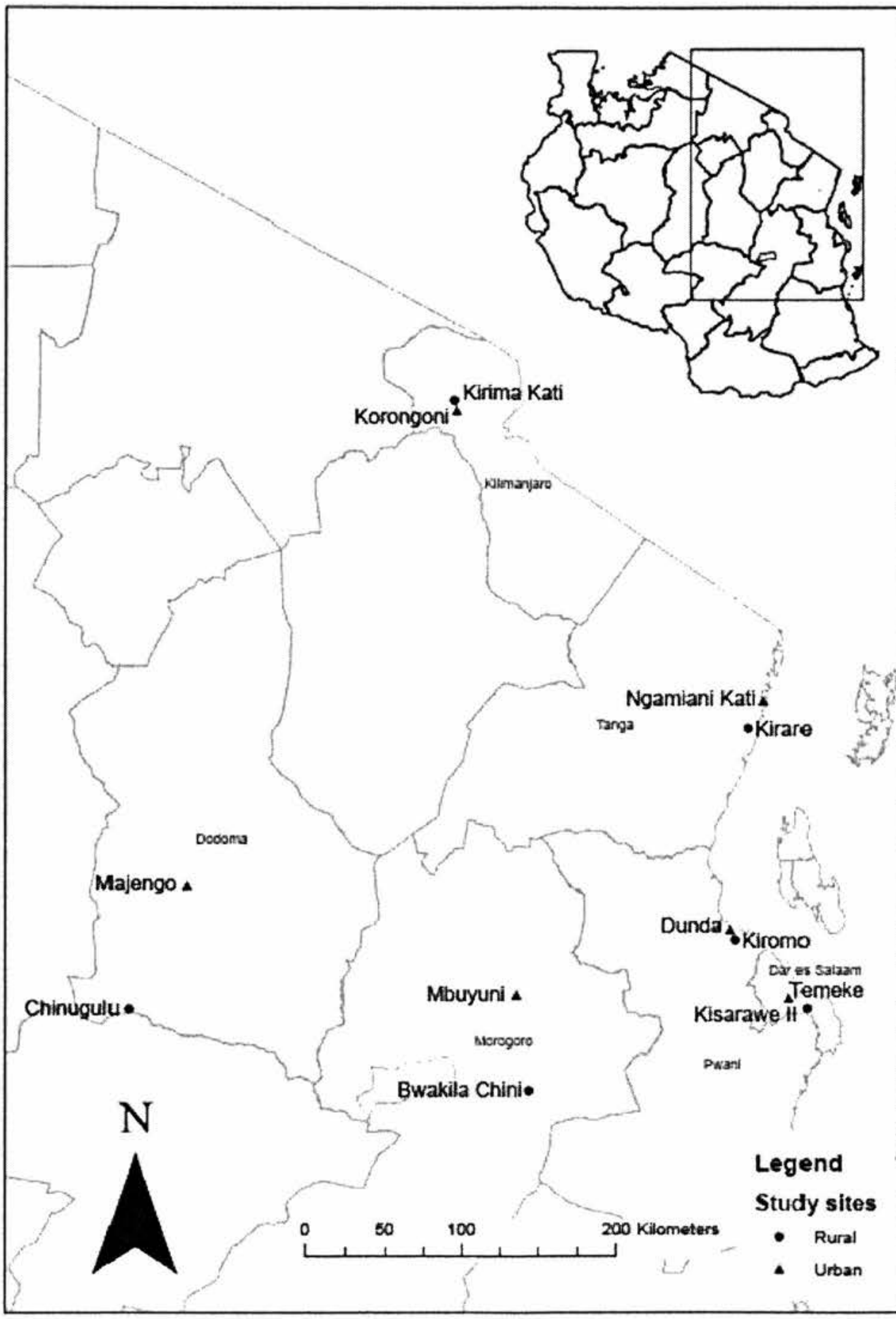

Figure 3.1. Map of Tanzania showing the 12 study sites selected from three coastal and three inland regions

The relationships between potential predictors and dog ownership status were examined using univariable logistic regression. Factors with a likelihood-ratio test p value of ≤ 0.25 were considered for entry into a multivariable logistic regression model. Prior to this, multicollinearity between these selected variables was assessed using Pearson's Chi-squared or (when the expected count in any category of the contingency table was less than five) Fisher's exact tests, and through examination of the generalized variance inflation factors when all variables were entered into a preliminary main effects logistic regression model. The variance inflation factor assesses the effect of entering a new variable into a model on the variance of the coefficients for variables currently in the model, and is a measure of the independence of predictor variables from each other. Variables exhibiting high collinearity were either combined to form new variables, or were excluded from the model. This decision was based upon assessment of the potential functional relationships between the variables and consideration of causal effects of dog ownership. Four household socio-demographic variables (level of education and age of head of household, asset quintile and number of occupants) were found to be highly collinear. Hierarchical cluster analysis using Ward's minimum variance method was used to group these into a single new variable, household socio-demographic type, with five levels. In Ward's minimum variance method, the distance between two clusters is the total of the analysis of variance (ANOVA) sum of squares between the two clusters, summed across all four household variables. This method builds the hierarchy from the individual elements by progressively merging clusters such that, at each generation, the within-cluster sum of squares is minimized for all partitions obtainable by merging two clusters from the previous generation (Ward, 1963). Two variables relating to gender (sex of head of household and presence of an adult male occupant) were combined, as were the variables relating to the presence and sex of children in the household. Ownership of cattle and/or small stock (sheep and goats) was combined into a single dichotomous variable, livestock ownership. One variable (whether the respondent was the head of the household or not) was excluded from the model. This variable was found to be highly collinear with a number of independent variables, but was considered to be causally unrelated to dog ownership.

A multivariable logistic regression model of dog ownership was constructed by backward stepwise selection of variables. Variables were retained in the model if the likelihood-ratio test p values were <0.05. The Wald test p-value was used when comparing categories with the reference category. The potential confounding effects of those variables not retained in the final model were assessed by refitting each variable in succession into the final model and inspecting the percentage change in the odds ratios of the retained variables. A variable was deemed a confounder if it resulted in >20% change in the odds ratio (Dohoo *et al.*, 2003). All two-way interaction terms between variables in the final main effects model were assessed, again using backward stepwise selection. Finally, the effect of the study design was taken into account by entering study site as a random effect in the model and examining the impact on the coefficients estimated in the single-level model. Statistical analysis was done using R version 2.4.1 (The R Foundation for Statistical Computing, http://www.r-project.org).

3.2.3 Fit of the model and regression diagnostics

The fit of the final fixed-effects model was assessed using the Hosmer-Lemeshow goodness-of-fit test (Hosmer & Lemeshow, 2000), and its predictive ability determined by generating a receiver operator characteristic (ROC) curve. Regression diagnostics were performed on the model to identify covariate patterns with the greatest delta beta (a measure of the effect of each covariate pattern on the value of the estimated parameters) and delta χ^2 (a measure of the effect of each covariate pattern on the fit of the model) values. Households with these covariate patterns were then removed from the model and the change in the value of the coefficients was examined (Hosmer & Lemeshow, 2000).

3.3 Results

3.3.1 Dog ownership patterns

A total of 1,471 households were interviewed between October 2004 and July 2005 (9.7% of 15,220 identified households across 12 study sites), of which 202 (13.7%) were dog-owning households (DOHH). Within the sample of DOHH, 81 households (40%) owned one dog, 72 (36%) two dogs, 13 (6%) three dogs, and the remainder owned between 4-12 dogs each (Figure 3.2; mean number of dogs per DOHH 2.38 95% CI 2.34-2.42). A breakdown of the dog ownership patterns by study site is given in Table 3.1. Of the 1,072 non-dog-owning households (NOHH) who gave a reason for non-ownership, 29.2% said they disliked dogs, 26.4% felt they lacked the time and/or space to take care of a dog, 17.4% did not feel the necessity of having a dog, 10.9% had not yet replaced a previous dog that had died or disappeared, 8.6% stated that it was against their cultural or religious views and 7.5% felt that dogs were too expensive to acquire and look after.

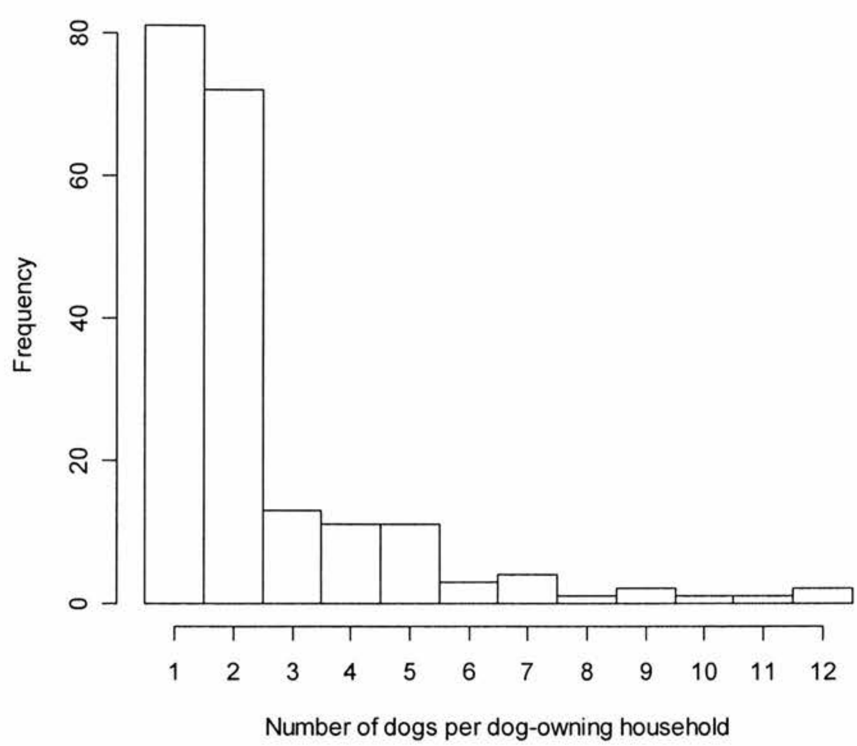

Figure 3.2. The distribution of dogs per dog-owning household (DOHH) in the cross-sectional sample of households in Tanzania

Table 3.1. Patterns of dog ownership across 12 study sites in Tanzania. DOHH = Dog-owning households. Figures in bold are mean and 95% confidence intervals (in parentheses) derived from 10,000 bootstrap samples of the original data

	Urban						Rural					
	Inland			Coastal			Inland			Coastal		
Study site	Koro	Maje	Mbuy	Dund	Ngam	Teme	Bwak	Chin	Kiri	Kira	Kiro	Kisa
% DOHH	16.8	14.1	14.7	10.3	8.1	2.5	22.0	12.7	33.8	18.1	11.5	19.4
		15.1 (14.1-16.0)			**7.1 (6.5-7.8)**			**23.9 (22.1-25.8)**			**16.4 (14.8-18.1)**	
			11.5 (10.9-12.1)						**20.1 (18.9-21.4)**			
						13.7 (13.2-14.3)						
Households per dog	2.7	2.7	3.6	3.1	8.9	32.6	1.2	3.9	1.4	2.3	3.1	2.3
		3.0 (2.7-3.2)			**5.8 (5.1-6.7)**			**1.6 (1.5-1.8)**			**2.5 (2.2-2.8)**	
			3.8 (3.6-4.1)						**2.0 (1.8-2.1)**			
						3.1 (2.9-3.2)						
Humans per dog	15.4	8.3	11.1	11.0	78.6	214.6	6.6	17.5	5.3	8.3	11.7	14.0
		14.4 (13.2-15.7)			**27.2 (23.9-31.1)**			**7.6 (6.8-8.6)**			**10.8 (9.5-12.3)**	
			18.0 (16.8-19.4)						**8.9 (8.2-9.7)**			
						14.3 (13.5-15.1)						

3.3.2 Factors affecting dog ownership

The results of the univariable analysis of the effects of both the original and combined variables on dog ownership status are presented in Table 3.2. The household socio-demographic types identified using hierarchical cluster analysis (see Methods) are summarised in Table 3.3. The effect of different groupings of age of the head of the household on the odds of dog ownership is given in Table 3.4. In the final multivariable mixed-effect model (Table 3.5), dog ownership was significantly associated with the gender composition of the adult members of the household, household socio-demographic type, possession of poultry, cat ownership, religion of the head of the household and livestock ownership. The odds of dog ownership were greater in male-led households when compared to households in which no adult male was present (OR 3.5, 95% CI 1.7-7.2). Compared to household socio-demographic type 1, the odds of dog ownership were greater in type 4 households (better educated, wealthier, larger households; OR 2.8 95% CI 1.5-5.0) and type 5 households (moderately wealthier, larger households, older household heads; OR 3.1 95% CI 1.8-5.3). Cat-owning households had greater odds of dog ownership (OR 2.0 95% CI 1.2-3.3), as did households which kept poultry (OR 2.0 95% CI 1.4-2.9), when compared to non-cat and -poultry owning households, respectively. One interaction term, between livestock ownership and religion, was significant in the final model. Among non-livestock-owning households, Muslim households had lower odds of dog ownership than Christian households (OR 0.3 95% CI 0.2-0.4); however, among livestock-owning households there was no effect of religion on dog ownership (OR 0.9 95% CI 0.4-1.9). Livestock ownership increased the log odds of dog ownership by 0.8 in Christian households (OR 2.1 95% CI 1.2-3.7) and by 1.9 in Muslim households (OR 6.4 95% CI 3.1-13.1).

Adding study site as a random effect in a generalised linear mixed-effects model containing the selected variables and interaction term as fixed effects resulted in minimal changes (<9%) to the coefficients and standard errors compared to the single-level model. Although there was no evidence to reject the null hypothesis of no random variation between study sites (likelihood-ratio test P = 0.07, d.f. = 1, one-sided alternative hypothesis) (Snijders & Bosker, 1999), the random effect of study site was retained in the final model in accordance with the hierarchical nature of the study design (Dohoo *et al.*, 2003). Table 3.4 presents the results of this mixed-effects model.

The fixed-effects multivariable model appeared to fit the data adequately (Hosmer-Lemeshow goodness-of-fit test statistic = 9.99, d.f. = 8, P = 0.29). The ROC curve is shown in Figure 3.3. The area under the curve was 0.80, indicating the model has good predictive ability. Four influential covariate patterns were identified (Figure 3.4). Removal from the model of households within two of these covariate patterns had minimal impact on the estimated coefficients (<15%). The two remaining covariate patterns had large values of delta beta and delta χ^2 (measures of the effect of covariate patterns on regression coefficients and fit of the model, respectively).

Table 3.2. Univariable analysis of factors associated with dog ownership in Tanzania

Variable	Total (n = 1471)	DOHH (%) (n = 202)	NOHH (%) (n = 1269)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Sex of head of household								
Female	613	47 (23)	566 (45)				1(REF)	
Male	855	155 (77)	700 (55)	0.98	0.176	**< 0.001**	2.67	1.89-3.76
Missing	3	0	3					
Age of head of household (years)						**< 0.001**		
<25	150	11 (5)	139 (11)				1(REF)	
25-34	352	30 (15)	322 (25)	0.16	0.367	0.65	1.18	0.57-2.42
35-44	353	41 (20)	312 (25)	0.51	0.355	0.15	1.66	0.83-3.33
45-54	266	56 (28)	210 (17)	1.21	0.348	<0.001	3.37	1.71-6.66
55-64	167	27 (13)	140 (11)	0.89	0.377	0.02	2.44	1.16-5.10
65-74	99	21 (10)	78 (6)	1.22	0.398	0.002	3.40	1.56-7.43
75+	77	15 (7)	62 (5)	1.12	0.425	0.009	3.06	1.33-7.04
Missing	7	1	6					
Occupation of head of household								
Elementary	794	114 (58)	680 (54)				1(REF)	
Secondary	660	84 (42)	576 (46)	-0.14	0.155	**0.37**	0.87	0.64-1.18
Missing	17	4	13					
Level of education of head of household								
None	184	26 (13)	158 (13)				1(REF)	
Primary	927	101 (51)	826 (65)	-0.30	0.236	0.21	0.74	0.47-1.18
Secondary	232	43 (22)	189 (15)	0.32	0.271	0.23	1.38	0.81-2.35
Tertiary	118	27 (14)	91 (7)	0.59	0.305	0.05	1.80	0.99-3.28
Missing	10	5	5					
Religion of head of household								
Christian	598	127 (66)	471 (37)				1(REF)	
Muslim	852	66 (34)	786 (63)	-1.16	0.163	**<0.001**	0.31	0.23-0.43
Missing	21	9	12					
Number of household occupants						**< 0.001**		
1	89	4 (2)	85 (7)				1(REF)	
2	135	10 (5)	125 (10)	0.53	0.608	0.38	1.70	0.52-5.60
3	247	20 (10)	227 (18)	0.63	0.562	0.26	1.87	0.62-5.64
4	315	40 (20)	275 (22)	1.13	0.539	0.04	3.09	1.08-8.89
5	217	28 (14)	189 (15)	1.15	0.550	0.04	3.15	1.07-9.26
6	175	26 (13)	149 (12)	1.31	0.554	0.02	3.71	1.25-10.98
7+	288	74 (37)	214 (17)	1.99	0.526	<0.001	7.35	2.62-20.60
Missing	5	0	5					

Variable	Total (n = 1471)	DOHH (%) (n = 202)	NOHH (%) (n = 1269)	Coefficient	Standard error	p-value*	Odds ratio (OR)	95% confidence interval (CI)
Household asset quintile						**< 0.001**		
1	277	44 (22)	233 (19)				1(REF)	
2	290	23 (12)	267 (21)	-0.78	0.273	0.004	0.46	0.27-0.78
3	292	35 (18)	257 (21)	-0.33	0.244	0.18	0.72	0.45-1.16
4	296	27 (14)	269 (22)	-0.63	0.260	0.02	0.53	0.32-0.89
5	290	71 (36)	219 (18)	0.54	0.214	0.01	1.72	1.13-2.61
Missing	26	2	24					
How long in area?								
≥1 year	1346	187 (97)	1159 (94)				1(REF)	
<1 year	75	6 (3)	69 (6)	-0.62	0.433	**0.12**	0.54	0.23-1.26
Missing	50	9	41					
Is the respondent the head of household?								
No	350	83 (41)	267 (21)				1(REF)	
Yes	1121	119 (59)	1002 (79)	-0.96	0.159	**<0.001**	0.38	0.28-0.52
Presence of a male adult occupant								
No	234	10 (5)	224 (18)				1(REF)	
Yes	1232	192 (95)	1040 (82)	1.42	0.333	**<0.001**	4.14	2.15-7.94
Missing	5	0	5					
Presence of a female adult occupant								
No	98	11 (5)	87 (7)				1(REF)	
Yes	1368	191 (95)	1177 (93)	0.25	0.329	**0.44**	1.28	0.67-2.45
Missing	5	0	5					
Presence of children (<16 years)								
No	357	41 (20)	316 (25)				1(REF)	
Yes	1109	161 (80)	948 (75)	0.27	0.187	**0.14**	1.31	0.91-1.89
Missing	5	0	5					
Presence of a male child occupant								
No	639	69 (34)	570 (45)				1(REF)	
Yes	827	133 (66)	694 (55)	0.46	0.159	**0.003**	1.58	1.16-2.16
Missing	5	0	5					
Presence of a female child occupant								
No	690	88 (44)	602 (48)				1(REF)	
Yes	776	114 (56)	662 (52)	0.16	0.153	**0.28**	1.18	0.87-1.59
Missing	5	0	5					
Ownership of cattle								
No	1383	157 (78)	1226 (97)				1(REF)	
Yes	86	45 (22)	41 (3)	2.15	0.232	**<0.001**	8.57	5.44-13.50
Missing	2	0	2					
Ownership of small stock (sheep/goats)								
No	1358	159 (79)	1199 (95)				1(REF)	
Yes	111	43 (21)	68 (5)	1.56	0.212	**<0.001**	4.77	3.15-7.23
Missing	2	0	2					

Variable	Total (n = 1471)	DOHH (%) (n = 202)	NOHH (%) (n = 1269)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Ownership of poultry								
No	1041	95 (47)	946 (75)				1(REF)	
Yes	428	107 (53)	321 (25)	1.20	0.155	**<0.001**	3.32	2.45-4.50
Missing	2	0	2					
Ownership of pigs								
No	1455	196 (97)	1259 (99)				1(REF)	
Yes	14	6 (3)	8 (1)	1.57	0.545	**0.007**	4.82	1.65-14.03
Missing	2	0	2					
Ownership of cat/s								
No	1349	171 (85)	1178 (93)				1(REF)	
Yes	120	31 (15)	89 (7)	0.88	0.224	**<0.001**	2.40	1.55-3.72
Missing	2	0	2					
Ownership of other animals								
No	1432	189 (94)	1243 (98)				1(REF)	
Yes	37	13 (6)	24 (2)	1.27	0.353	**<0.001**	3.56	1.78-7.12
Missing	2	0	2					
				COMPOSITE VARIABLES:				
Adult gender composition						**< 0.001**		
No adult male occupant	225	9 (4)	216 (17)				1(REF)	
Female head; adult male occupant/s	384	38 (19)	346 (27)	0.97	0.381	0.01	2.64	1.25-5.56
Male head	855	155 (77)	700 (55)	1.67	0.352	<0.001	5.31	2.67-10.58
Missing	7	0	7					
Household socio-demographic type						**< 0.001**		
1	365	28 (14)	337 (27)				1(REF)	
2	297	30 (15)	267 (21)	0.30	0.275	0.27	1.35	0.79-2.32
3	349	44 (22)	305 (24)	0.55	0.254	0.03	1.74	1.05-2.86
4	213	39 (19)	174 (14)	0.99	0.265	<0.001	2.70	1.61-4.53
5	247	61 (30)	186 (15)	1.37	0.246	<0.001	3.95	2.44-6.39
Composition of child occupants						**0.014**		
Both sexes	494	86 (43)	408 (32)				1(REF)	
Female only	282	28 (14)	254 (20)	-0.65	0.232	0.005	0.52	0.33-0.82
Male only	333	47 (23)	286 (23)	-0.25	0.197	0.21	0.78	0.53-1.15
No children	357	41 (20)	316 (25)	-0.49	0.204	0.02	0.62	0.41-0.92
Missing	5	0	5					
Ownership of livestock (cattle/sheep/goats)								
No	1321	140 (69)	1181 (93)				1(REF)	
Yes	148	62 (31)	86 (7)	1.81	0.189	**<0.001**	6.08	4.20-8.81
Missing	2	0	2					

*Bolded *p*-values are likelihood ratio test *p*-values and unbolded *p*-values are Wald test *p*-values. REF = Reference category.

Table 3.3. Household socio-demographic types derived from hierarchical cluster analysis of age and level of education of the head of the household, number of occupants in the household (household size) and asset quintile score (AQ, with 1 = poorest and 5 = least poor)

Type 1 Less well educated (21% none, 67% primary school only); less wealthy (92% AQ1-3, with 31% AQ1); smaller households (80% <4 occupants); younger household heads (80% <55 years, with 47% <35 years)
Type 2 Moderately educated (40% secondary/tertiary education, 58% primary school only); wealthy (94% AQ4-5, with 44% AQ5); smaller households (all <5 occupants, with 50% having only 2-3 occupants); younger household heads (60% 25-44 years)
Type 3 Less well educated (10% none, 80% primary school only); less wealthy (all AQ1-3, with 39% AQ1); larger households (all 4+ occupants, with 27% 7+); younger household heads (all <65 years, with 35% <35 years)
Type 4 Better educated (50% secondary/tertiary education, 49% primary only); wealthy (95% AQ4-5, with 50% AQ5); larger households (all 5+ occupants, with 33% 7+); younger household heads (all <55 years, with 30% <35 years)
Type 5 Less well educated (25% none, 54% primary school only); moderately wealthy (50% AQ3-4); larger households (all 4+ occupants, with 50% 7+); older household heads (all 45+ years)

Table 3.4. Univariable analysis of the effect of different groupings of age on the odds of dog ownership in the study sample

Variable	Total (n = 1471)	DOHH (%) (n = 202)	NOHH (%) (n = 1269)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Age of head of household (years)						**< 0.001**		
<25	150	11 (5)	139 (11)				1(REF)	
25-34	352	30 (15)	322 (25)	0.16	0.367	0.65	1.18	0.57-2.42
35-44	353	41 (20)	312 (25)	0.51	0.355	0.15	1.66	0.83-3.33
45-54	266	56 (28)	210 (17)	1.21	0.348	<0.001	3.37	1.71-6.66
55-64	167	27 (13)	140 (11)	0.89	0.377	0.02	2.44	1.16-5.10
65-74	99	21 (10)	78 (6)	1.22	0.398	0.002	3.40	1.56-7.43
75+	77	15 (7)	62 (5)	1.12	0.425	0.009	3.06	1.33-7.04
Missing	7	1	6					
Age of head of household (years)						**< 0.001**		
<23	96	6 (3)	90 (8)				1(REF)	
23-32	350	31 (16)	319 (26)	0.38	0.462	0.41	1.46	0.59-3.60
33-42	367	41 (21)	326 (26)	0.63	0.453	0.16	1.89	0.78-4.58
43-52	272	51 (26)	221 (18)	1.24	0.449	0.006	3.46	1.43-8.35
53-62	188	36 (18)	152 (13)	1.27	0.461	0.006	3.55	1.44-8.76
63-72	105	19 (10)	86 (7)	1.20	0.492	0.01	3.31	1.26-8.69
73+	86	17 (9)	69 (6)	1.31	0.501	0.009	3.70	1.38-9.87
Missing	7	1	6					
Age of head of household (years)						**< 0.001**		
<23	96	6 (3)	90 (8)				1(REF)	
23-27	148	10 (5)	138 (11)	0.08	0.534	0.88	1.09	0.38-3.09
28-32	202	21 (11)	181 (15)	0.55	0.481	0.25	1.74	0.68-4.46
33-37	184	17 (9)	167 (14)	0.42	0.493	0.39	1.53	0.58-4.01
38-42	183	24 (12)	159 (13)	0.82	0.475	0.09	2.26	0.89-5.75
43-47	138	24 (12)	114 (10)	1.15	0.478	0.02	3.16	1.24-8.05
48-52	134	27 (14)	107 (9)	1.33	0.473	0.005	3.79	1.50-9.57
53-57	94	20 (10)	74 (6)	1.40	0.491	0.004	4.05	1.55-10.62
58-62	94	16 (8)	78 (7)	1.12	0.503	0.03	3.08	1.15-8.25
63-67	58	9 (5)	49 (4)	1.01	0.556	0.07	2.76	0.93-8.19
68-72	47	10 (5)	37 (3)	1.40	0.552	0.01	4.05	1.37-11.96
73+	86	17 (9)	69 (6)	1.31	0.501	0.009	3.70	1.38-9.87
Missing	7	1	6					

*Bolded *p*-values are likelihood ratio test *p*-values and unbolded *p*-values are Wald test *p*-values. REF = Reference category.

Table 3.5. Multivariable mixed-effects logistic regression model of factors associated with dog ownership in Tanzania, with study site as a random effect (n = 1,471). Random effects variance estimate = 0.08 (standard deviation = 0.28)

Variable	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval
Adult gender composition			**< 0.001**		
No adult male occupant				1 (REF)	
Female head; adult male occupant/s	0.64	0.402	0.12	1.90	0.87-4.18
Male head	1.26	0.366	<0.001	3.52	1.72-7.20
Household socio-demographic type			**< 0.001**		
Type 1				1 (REF)	
Type 2	0.38	0.311	0.22	1.46	0.79-2.69
Type 3	0.21	0.279	0.45	1.24	0.72-2.13
Type 4	1.01	0.302	<0.001	2.75	1.52-4.98
Type 5	1.12	0.278	<0.001	3.08	1.78-5.32
Ownership of poultry			**< 0.001**		
No				1 (REF)	
Yes	0.69	0.194	< 0.001	1.99	1.36-2.91
Ownership of cat/s			**0.01**		
No				1 (REF)	
Yes	0.68	0.265	0.01	1.97	1.18-3.32
Ownership of livestock					
No				1 (REF)	
Yes	0.75	0.417	0.01	2.11	1.20-3.73
Religion of head of household					
Christian				1 (REF)	
Muslim	-1.23	0.208	< 0.001	0.29	0.19-0.44
Interaction between livestock ownership and religion	1.11	0.445	**0.02**	3.02	1.26-7.23
Intercept	-3.38	0.417			

*Bolded *p*-values are likelihood ratio test *p*-values and unbolded *p*-values are Wald test *p*-values. REF = Reference category.

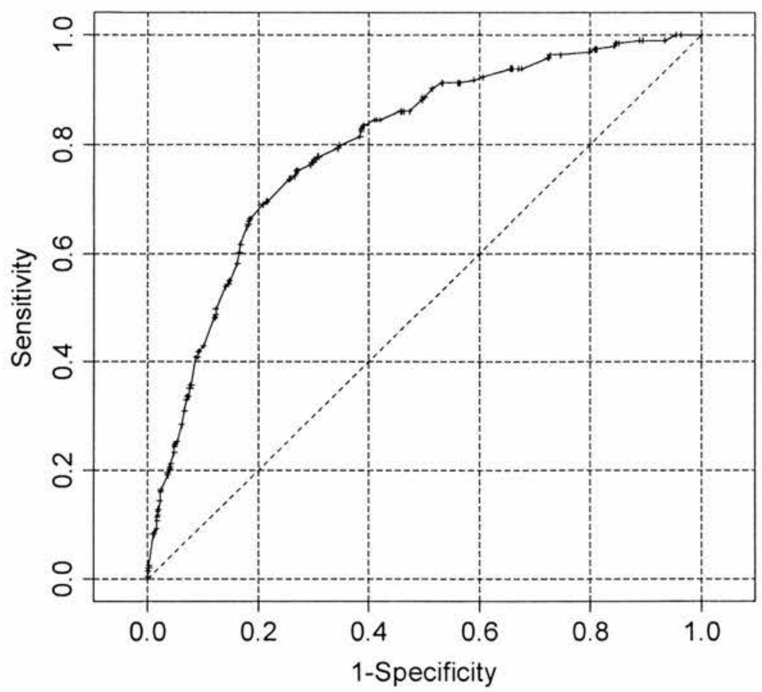

Figure 3.3. Receiver-operator characteristic (ROC) curve for the fitted fixed-effects model. The area under the curve is 0.80.

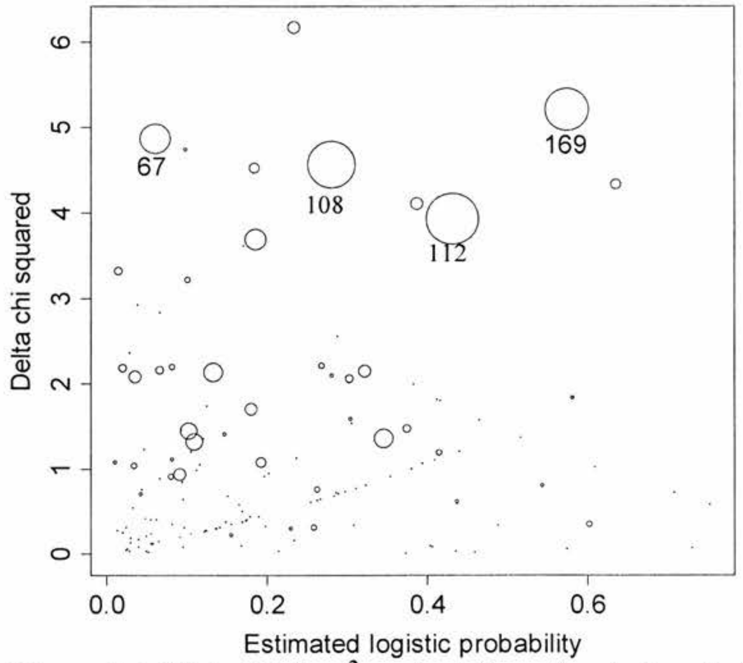

Figure 3.4. Plot of delta χ^2 against the estimated probability from the fitted fixed-effects model. The size of the plotting symbols is proportional to delta beta. $J = 170$ covariate patterns, with four influential covariate patterns identified.

3.4 Discussion

This paper presents the results of the first study of patterns and predictors of dog ownership in Tanzania. The numbers of owned dogs are similar to those reported elsewhere in sub-Saharan Africa (Brooks, 1990; Rautenbach *et al.*, 1991; de Balogh *et al.*, 1993; Edelstein, 1995; Laurenson *et al.*, 1997; Kitala *et al.*, 2001), with the point estimates for human:dog ratios falling within the 95% confidence intervals of estimates from a meta-analysis of data from both urban and rural settings in Africa (Knobel *et al.*, 2005). The overall proportion of dog-owning households identified in the study sample (13.7%) is lower than reported national estimates from non-African countries including the United States (36.1%, Wise *et al.*, 2002), Japan (24.2%, Inaba, 1998), Taiwan (22.9%, Hsu *et al.*, 2003), and Sweden (15.5%, Egenvall *et al.*, 1999). However, the mean number of dogs per dog-owning household (2.2) is higher, with a lower proportion of dog-owning households only keeping a single dog (40%). Corresponding figures for other countries are: United States 1.7 & 63%, Taiwan 1.6 & 69.5%, Sweden 1.4 & 77.9%. The variation seen in the proportion of households owning dogs, with rural areas having a high proportion of dog-owning households and coastal urban areas in particular displaying the inverse, reflects the geographic heterogeneity in the distribution of factors operating at a household level: livestock keeping is more common in rural than in urban areas (69.7% of rural households in this study engaged in some form of livestock keeping, compared to 18.2% of urban households), and a higher proportion of Tanzania's coastal population are Muslim (77.6% vs. 40.8% in inland areas – data from this study).

Several other studies have reported an association between the adult gender composition of a household and dog ownership. In contrast to the present study, Westgarth *et al.* (2007) found that it was the presence of an adult female in the household that was positively associated with ownership among a semi-rural population in the UK. Similarly, a study of young, single-member households in the U.S.A. determined that females were more likely to own dogs (Wise & Kushman, 1984). These results reflect the generally higher degree of attachment to companion animals exhibited by females in several North American and European studies (Kidd & Kidd, 1989; Schenk *et al.*, 1994; Vidovic *et al.*, 1999; Robertson *et al.*, 2004; Bagley & Gonsman, 2005). It has been shown that the sex of the head of the household is highly correlated with several other factors which may predict dog ownership. Katapa (2006) found that female-headed households in Tanzania were more likely to have children under the age of five, fewer than six occupants, fewer adult males, no radio (a common household asset in the current study) and to be generally poorer than male-headed households. Although similar associations were seen when testing for collinearity among independent variables in the current study, these were accounted for in the model-building process, suggesting that there is an inherent association between male-led households and dog ownership. This view is supported by the results of a related study assessing owners' attitudes towards dogs, based on the same population sample as the current study, which showed that male respondents had a significantly more positive attitude towards dogs than females (Chapter 4, this volume). Other studies in non-Western countries have found a similar relationship. In a random telephone survey in Taiwan, Hsu *et al.* (2003) found that male respondents were more likely to report having ever owned a dog than females, and in Kuwait, Al-Fayez *et al.* (2003) reported that males had a more positive attitude towards companion animals, as measured on the Pet Attitude Scale (Templer *et al.*, 1981).

Although multicollinearity between independent variables can give rise to spurious results (Dohoo *et al.*, 1996), the problem has largely been ignored in the few studies examining the predictors of dog ownership among households (but see Westgarth *et al.*, 2007). The high degree of correlation between independent variables in the current study necessitated the formation of new, composite variables which make interpretation and comparison of results to previous studies less straightforward. Nevertheless, broad patterns can be identified. Socio-demographic type 4 and 5 households were more likely to own dogs than other household types. Type 4 households were almost exclusively urban households (99%). When compared to the other major category of urban households, type 2 (99% of all type 2 households were also urban), the major distinction is in household size, with type 4 households all having five or more occupants (Table 3.3). Type 5 households also tended to be larger households, with half having seven or more occupants. This association between household size and dog ownership has been consistently reported across studies (Franti *et al.*, 1974; Franti *et al.*, 1980; Troutman, 1988; Teclaw *et al.*, 1992; Wise & Yang, 1992; Hsu *et al.*, 2003; Westgarth *et al.*, 2007), although only the latter two studies employed a multivariable approach. In the univariable analysis in the current study, the number of occupants in a household was strongly associated with the household's asset quintile, the age of its head occupant and the likelihood of livestock ownership. Larger households usually consist of several related family units, the oldest (usually male) member of which tends to be deferred to as the household head. Because asset score and livestock ownership are measured at a household level, rather than on a *per capita* basis, it is also unsurprising that larger households would rank higher in these aspects. Despite these complex interrelationships, the hierarchical cluster analysis does suggest an effect of household size *per se* on dog ownership. It also suggests that dog-owning households tend to have higher asset quintile scores (with the exception of type 2 households: smaller, wealthy urban households). This association between dog-ownership and a proxy measure of household income is a finding common to a number of American studies (Franti *et al.*, 1974; Franti *et al.*, 1980; Troutman, 1988; Teclaw *et al.*, 1992; Wise & Yang, 1992). However, this does not extend to an association with occupation classification, which was shown to be non-significant in the current study and in multivariable analyses by both Leslie *et al.* (1994) and Westgarth *et al.* (2007). The latter authors concluded that the effects of occupation or income are likely to be intertwined with other household characteristics, primarily life stage grouping (Wise & Kushman, 1984). This conclusion is supported by the hierarchical cluster analysis of household types presented here, and highlights the importance of examining and reporting unconditional associations between variables after multivariable analysis.

Cultural materialism is an anthropological school of thought "based on the simple premise that human social life is a response to the practical problems of earthly existence" (Harris, 1979). While the association demonstrated between dog- and livestock-ownership fits with the cultural-materialist view of pet keeping commonly invoked to explain the phenomenon in non-Western societies (Harris, 1990), wherein it is assumed that pets are kept by a society solely if doing so results in a net increase to the efficiency of that society's production system, the interpretation of this finding may not be straightforward. In a survey of dog-owning households in the 12 study sites, it was found that only 12.7% (75/591) of livestock-owning households gave as their primary reason for owning dogs "To protect livestock against predators". The majority (61.9%) reported keeping dogs "To guard the household against human intruders", as did the majority (76.4%) of non-livestock-owning households. A higher proportion of livestock owners did report keeping dogs to chase pests away from crops (23.5% vs. 15.2% of non-livestock-owning households), reflecting the largely mixed agro-pastoralist production systems in the non-urban areas of this study. While these findings by no means refute a cultural-materialist viewpoint, they do suggest that other factors, possibly associated with broader constructs related to rural lifestyles in general (e.g. attitudes towards animals) rather than livestock keeping alone, may be in operation.

Whatever the association between livestock and dog ownership, it seems strong enough to override pre-existing aversions to dogs due to religious backgrounds. In Islam, dogs are traditionally considered impure, although dog ownership itself is not proscribed (Foltz, 2005). This is reflected in the significantly lower odds of dog ownership among Muslim households, compared to their Christian counterparts. However, among livestock-owning households this distinction no longer holds, with respondents of either religion being equally likely to own dogs. Livestock ownership greatly increases the odds of a Muslim household owning dogs. This does provide evidence for a utilitarian role for dogs among livestock owners, the benefits of which outweigh any religious considerations.

Regression diagnostics revealed two influential covariate patterns, with large negative Pearson residuals, suggesting that a higher proportion of households with these covariate patterns were predicted to be dog-owning than was the case. Re-examination of the data showed that 50% (10/20) of non-owning households with these two covariate patterns gave as their reason for non-ownership, "Previous dogs died/disappeared and have not yet been replaced", compared to just 10% of households within other covariate patterns. There is thus an inclination towards dog ownership within these households, supporting the predictive ability of the model.

3.5 Conclusions

It is hoped that the results presented in this paper may assist veterinary and public health officials in the planning and implementation of rabies control programmes in Tanzania and elsewhere. The consistent results of human:dog ratios across studies, together with the identification of large-scale proxies for household-level predictors (primarily urban/rural and coastal/inland) suggest that crude estimates of dog numbers could be obtained by extrapolation from human population figures through application of the relevant ratio. This will allow more accurate estimation and targeting of resources for national-level rabies control programmes, and may assist with the prediction of potential rabies 'hot-spots' or outbreak zones. Identification and understanding of household-level predictors of dog ownership will also permit the focused implementation of education and awareness campaigns that will be necessary to ensure the success of a national control strategy.

Ownership of domestic dogs is one of several behaviours relevant to canine rabies control that may be influenced by people's underlying attitudes towards dogs. Although this is an area of research that has received much attention in developed countries, very little work has been done in developing settings. The following chapter attempts to quantify attitudes towards dogs among owners in Tanzania, and to explore factors associated with these attitudes.

4 CHAPTER 4: DEVELOPMENT OF AN ITEM SCALE TO ASSESS ATTITUDES TOWARDS DOMESTIC DOGS IN THE UNITED REPUBLIC OF TANZANIA, AND ITS RELEVANCE FOR RABIES CONTROL

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4.1 Introduction

The ubiquity of domestic dogs in human societies around the world, and their typically close relationship with people, is testament to the benefits that humans derive from dogs. Such benefits may vary across cultures, and include elements of companionship, security, food acquisition, transport, leisure and even medical diagnostics and therapy (Hart, 1995; Serpell, 2000; Willis *et al.*, 2004). However, these benefits are offset by the potential detriments which dogs pose, ranging from minor annoyances such as fouling and noise pollution, to serious threats to human health, including bite wounds and the transmission of infectious diseases. Among human populations, the risk of exposure to such hazards may vary, influenced by the attitudes and behaviours of people towards dogs. For example, among the Turkana of northern Kenya, a close association between humans and dogs provides ideal conditions for the transmission of the parasite *Echinococcus granulosus*, leading to a high incidence of hydatid disease among this population (Watson-Jones & Macpherson, 1988). Across cultures, male children are generally at higher risk of dog bite injuries, due in part to their closer association with dogs (Weiss *et al.*, 1998).

Domestic dogs are the main reservoir hosts for rabies virus in many parts of the world, and more than 90% of human rabies cases derive from exposure to infected dogs (World Health Organization, 1999). The central role played by domestic dogs is a significant feature in the epidemiology of rabies in many developing countries, particularly those of Asia and sub-Saharan Africa (Knobel *et al.*, 2005). Control of the disease in these areas where canine rabies is endemic is focused primarily on the vaccination of owned domestic dogs (Knobel *et al*., 2007). Attitudes and behaviour towards owned domestic dogs, particularly aspects of care-provision and physical handling, are thus of relevance to rabies control programmes in developing countries. For example, in Ethiopia the cost of dog rabies vaccination campaigns is increased by the fact that people are unable or highly reluctant to handle their dogs (Laurenson *et* al., 1997). Turnout at central point vaccination campaigns is thus low, necessitating costly house-to-house campaigns during which dogs must be caught and physically restrained by the vaccination team, increasing the risk of injury to both animal and handler.

While the study of human perceptions of animals is a field which is receiving increasing attention, none of the 52 studies on human-companion animal interactions evaluated by Barba (1995) were conducted in a developing country setting. Serpell (2004) postulated the existence of two primary motivational considerations of human attitudes towards animals, which he labelled 'affect', representing people's emotional responses towards animals, and 'utility', representing people's perceptions of animals' instrumental value. The common assumption with respect to dog ownership in sub-Saharan Africa is that people will demonstrate very strong utility and weak affective orientations; in other words, people have a largely 'utilitarian' view of domestic dogs and that this is reflected in aspects of dog ownership and care-provision, including vaccination. At present, few studies have examined this hypothesis, the factors which may influence such attitudes, or their implications for rabies control. One reason for this may be that the standardized instruments and techniques used to evaluate attitudes towards companion animals (compiled in Anderson, 2007) have not been validated for use in the social or cultural contexts encountered in developing countries.

An item scale is a measurement instrument comprising a collection of items combined into a composite score, intended to reveal levels of theoretical variables or constructs that are not readily observable by direct means (DeVellis, 2003): in this case, attitudes towards dogs. The objectives of the current study were to develop an item scale to measure attitudes towards owned domestic dogs in Tanzania, to assess the scale's reliability and validity, to conduct a preliminary analysis of factors affecting attitudes, and to explore the relevance of these attitudes to rabies control.

4.2 Methods

4.2.1 Scale development

An initial pool consisting of 32 five-point Likert scale items was constructed. Each item was presented as a declarative statement, followed by response options that indicated varying degrees of agreement with the statement (i.e. strongly agree, agree, neither agree nor disagree, disagree, strongly disagree). The underlying construct that guided the development of the scale was attitudes of dog-owners towards household dogs that pertained to aspects of attachment and physical handling. Some items were extracted from other studies (Templer *et al.*, 1981; Poresky *et al.*, 1987; Staats *et al.*, 1996), but many of the items were produced *de novo* following unstructured pilot interviews with dog owners and non-owners in an attempt to capture aspects peculiar to the socio-cultural context of Tanzania. Statements were composed in English, translated into Kiswahili, and then back-translated into English to check for retention of meaning (Brislin 1986). This procedure was repeated by revising the Kiswahili version until the back-translation matched the original English version. The item pool was then administered to a pilot sample of 195 dog-owning respondents from two urban (Moshi and Arusha towns), one rural (Simanjiro district) and one mixed (Karatu town) study site. Responses were then scored, favourable statements being scored 5 for 'strongly agree' down to 1 for 'strongly disagree'. The scoring was reversed for unfavourable statements; thus a high scale score reflects an overall positive attitude towards dogs. Each item's performance was then evaluated on the basis of its corrected item-scale correlation, that is, the correlation between the item in question and all the scale items, excluding itself. The 12 items with the highest corrected correlation coefficients were retained for use in the main study.

As DeVellis (2003) points out, this evaluation of each item's performance is at the heart of the scale development process, and as such deserves further explanation. Much of the following is derived from Devellis' text on the subject, particularly his chapters 2 and 5. The ultimate quality sought in an item is a high correlation with the true score of the latent variable. Using inferences based on classical measurement models under the assumption of parallel tests, it can be shown that the correlation between any two items is equal to the square of the correlation between either item and the true score. (The assumptions of the parallel tests model are that the amount of error associated with individual items varies randomly, error terms are not correlated between items or with the true score of the latent variable, the latent variable affects all items equally, and that each item has the same amount of error as any other item.) Thus it can be seen that the higher the correlations among items, the more intimately items are related to the true score (assuming that they share a common latent variable – this is later evaluated through factor analysis). To arrive at a set of highly intercorrelated items, each individual item should correlate substantially with the remaining items; hence the use of the corrected item-scale correlation.

There is no 'hard and fast' rule for scale length. A scale's alpha is influenced by two characteristics: the extent of covariation among the items and the number of items in the scale (DeVellis 2003). Thus longer scales are good because they tend to be more reliable; however, shorter scales are good because they place less of a burden on respondents. Twelve items were selected as a rather arbitrary cut-off as respondents were already being requested to answer a lengthy questionnaire. The effect on scale reliability of dropping the included items is shown in Table 4.1. Shortening either subscale would not have markedly improved alpha in any case, and in most cases would have markedly decreased it. Adding items would have been unlikely to increase alpha sufficiently to justify the increased burden of a lengthy scale on respondents, as unselected items had a substantially lower corrected item correlation coefficient than the average of the 12 selected items. As the reliability of the subscales is acceptable (at least against the admittedly subjective criterion proposed by Nunnally and Bernstein, 1994), it was not thought necessary to add additional items to the scale.

4.2.2 Questionnaire administration

Twelve sites were selected for the study, made up of six urban/rural pairs (Figure 3.1). Sites were defined as urban or rural on the basis of the 2002 Tanzanian census classification (National Bureau of Statistics 2004). Study sites were selected from each of three coastal (Dar es Salaam, Tanga and Pwani) and three inland regions (Kilimanjaro, Dodoma and Morogoro) in the United Republic of Tanzania. Within each region, the district containing the regional capital or major coastal city was selected, and from these a single urban ward was randomly selected. If the selected district contained a mix of urban and rural wards, then a single rural ward was also selected at random from the same district. If however the selected district was purely urban, then a rural ward was randomly selected from an adjacent rural district. Within selected wards, study site sizes were standardized such that urban sites contained 1,000-2,000 households, and rural sites 500-1,000. If the selected ward was too large, an appropriate number of contiguous administrative units (sub-wards) were selected as the study site. In this way, three study sites were selected in each of the four possible combinations of urban/rural and inland/coastal categories. These categories were chosen as they were believed to reflect possible differences in socio-cultural aspects of dog ownership, such as the economic status and religious beliefs of households. Within each study site, a dog rabies vaccination campaign was organized as part of a larger research project. Two days of central point vaccination (during which owners bring their dogs to an accessible vaccination station) were followed by house-to-house visits by vaccination teams until all known owned dogs were accounted for.

The 12 items selected during scale development were incorporated into a questionnaire on respondents' backgrounds, which included information on gender, age, occupation, religion, education and socio-economic status. Additional questions were included to assess the validity of the final attitude scale, in which respondents were asked to report the level of care-provision (frequency of feeding and type of food, veterinary care and grooming) and the level and frequency of physical contact with household dogs. The questionnaire was administered to one adult member (preferably the head of the household) of all known dog-owning households in the study site, following the rabies vaccination campaign. The vaccination status (not vaccinated, vaccinated at central point, vaccinated at house-to-house, or not eligible due to young age or previous vaccination history) of each dog within the household was also recorded. Questionnaires were administered to respondents by one of four trained interviewers (A, B, C & D) working for the project.

4.2.3 Subscale reliability

Scale reliability is the proportion of variance attributable to the true score of the latent variable (DeVellis, 2003). This reflects both the internal consistency of the scale (the degree to which the items of the scale have a strong relationship to their latent variable), and its temporal stability (or reproducibility), i.e. how constant scores remain from one occasion to another.

An exploratory factor analysis was conducted on the responses to determine the number of constructs underlying the set of items. Factor analysis begins with the premise that a single construct is sufficient to account for the observed pattern of responses. The procedure assesses how much of the association among individual items that single construct explains. It then identifies if a second construct explains some of the remaining covariation among items. Specifically, the process compares the correlation matrix for all individual items with the projected interitem correlations based on an assumption of a one-factor model. The proposed correlation is subtracted from the actual correlation to yield a residual correlation matrix, and the process is repeated to extract a second factor corresponding to a new latent variable. The appropriate number of factors was determined by applying the Very Simple Structure (VSS) criterion to the data (Revelle & Rocklin, 1979; complexity = 1). Following varimax rotation (an orthogonal rotation criterion which maximizes the variance of the squared elements in the columns of a factor matrix; see Kaiser, 1958 for more details), the items loading at more than 50% of the maximum loading on each factor were combined to form possible sub-scales. Cronbach alpha coefficients (Cronbach, 1951) were then computed as a measure of the internal reliability of the prospective subscales. Alpha is an indication of the proportion of variance in the scale score that is attributable to the true 'score' of the underlying construct. Nunnally & Bernstein (1994) suggest a value of 0.70 as a lower acceptable bound for alpha.

4.2.4 Subscale validity

In item scale theory, the validity of a particular scale concerns whether a given latent variable is indeed the underlying cause of item covariation. According to DeVellis (2003), validity is inferred from the manner in which the scale was constructed (content validity), its ability to predict specific events (criterion-related validity), or its relationship to measures of other constructs (construct validity). Content validity concerns the adequacy of item sampling, i.e. the extent to which a set of items reflects a content domain. Criterion-related validity implies an *empirical* (not necessarily causal) association with some criterion or 'gold standard', and may be predictive, concurrent, or even post-predictive. Finally, construct validity is concerned with the *theoretical* relationship of a variable (e.g. item scale score) to other variables, and thus differs from criterion-related validity primarily in invoking existing explanatory models of relationships between variables.

The concurrent validity (DeVellis, 2003) of the derived subscales in the current study was assessed by examining the strength of their empirical associations with self-reported levels of care and physical contact, recorded during the questionnaire. Standardized scores for the levels of care/physical contact were calculated for each household using the following methodology: responses for each item were given an ordinal score relative to an assumed ideal, e.g. for provision of food, never = 1, a few times a year = 2, a few times a month = 3, a few times a week = 4, one or more times a day = 5. A covariance matrix was then constructed for all the items and the eigenvector of the first eigenvalue was used as the 'raw' item score. Standardized household scores for each item where then calculated using the following formula, and summed for each household:

$$\left(\frac{\text{ordinal score of item} - \text{unweighted mean of item}}{\text{unweighted standard deviation of item}} \right) \times \text{raw item score}$$

I make the assumption that this score reflects behaviours that are in turn determined by underlying affective attitudes, and thus provides a measure of the concurrent validity of the subscales. Predictive validity was also assessed by examining the association between subscale scores and vaccination of dogs.

4.2.5 Statistical analysis

All analyses were performed in R 2.4.1. (The R Foundation for Statistical Computing, http://www.r-project.org). Reported 95% confidence intervals for alpha coefficients are adjusted bootstrap percentiles (two-sided nonparametric confidence intervals derived from 1,000 bootstrap replicates and adjusted for bias and skewness). Non-parametric, two-tailed tests were used to assess the univariable associations between the subscale scores and independent variables. Specific tests depended on the nature of the independent variable: Spearman's rank correlation was used for numerical data, and Wilcoxon's rank sum test and the Kruskal-Wallis test for categorical variables with 2 and >2 levels, respectively. The effect sizes of dichotomous categorical variables on attitude subscale score was estimated using Cohen's *d* (Rosnow and Rosenthal, 1996), the ratio of the difference between means divided by the pooled standard deviations of the two groups. Cohen (1988) justifies the following effect size thresholds for the statistic: 0.80 = large, 0.50 = medium and 0.20 = small. The effect of interviewer on the relationship between subscale score and care/physical contact score was assessed in an analysis of covariance (ANCOVA). An ANCOVA was deemed appropriate because, theoretically at least, it can be conceived that care/physical contact score is a measurement of a behaviour expressed at least partially as a result of an underlying attitude towards dogs, quantified by subscale score, and thus allows for a regression of care/physical contact score against subscale score, with interviewer as a categorical explanatory variable with four levels. In addition, ANCOVA is robust to the effects of departure from normality and (although to a lesser extent) homoscedasticity (Tan, 1987) and was therefore considered appropriate for the analysis of subscale score which, although left-skewed, still followed a reasonable bell-shaped distribution. The presentation of eligible dogs for vaccination at a central point was modelled as a binary response variable, as a relatively small number (6%) of households were found to have presented only a proportion of eligible dogs for vaccination. Thus if a household presented one or more eligible dogs, the response was positive, while if a household owned eligible dogs but did not present any at central point, the response was negative.

4.3 Results

4.3.1 Subscale reliability

The 12 items selected from the original pool during the scale development phase are shown in Table 4.1. The alpha coefficient of this item scale was 0.71 (95% CI:0.62-0.78) for the pilot sample (n = 194) and 0.74 (95% CI:0.71-0.79) for the study (n = 824). Two interpretable factors were identified through exploratory factor analysis of the study data: 1) acceptance of dogs as equals ('equality' subscale), and 2) physical interaction with household dogs ('handling' subscale). Inspection of item loadings after varimax rotation resulted in the reduction of the original six items in each factor to subscales of five items for Factor 1 (equality) and three items for Factor 2 (handling). The alpha coefficients for these subscales were 0.71 (95% CI:0.61-0.81) and 0.77 (95% CI:0.73-0.81), respectively (Table 4.1).

4.3.2 Subscale validity

Both subscales were significantly correlated with physical contact score (Spearman rank correlation coefficient: equality subscale $\rho = 0.19$, $P < 0.001$; handling subscale $\rho = 0.40$, $P < 0.001$). Equality subscale score was weakly correlated with care score ($\rho = 0.10$, $P = 0.005$). No correlation was found between handling subscale score and care score ($\rho = 0.01$, $P = 0.71$). The relationship between both subscale scores and care/physical contact score was found to be strongly determined by interviewer. An analysis of covariance (ANCOVA) revealed that a single interviewer, A, consistently

Table 4.1. The 12 items selected during the pilot phase, and the results of factor and reliability analyses following administration of the 12 items to a sample of 824 respondents

Item & subscale	Factor loading	Cronbach's α if item deleted
Equality subscale (α = 0.71)		
Our dog/s is/are a valuable possession	0.60	0.68
Our dog/s is/are an important part of the household	0.64	0.66
We like owning a dog	0.54	0.67
Our dog is a member of the family	0.58	0.65
You should treat your dog with as much respect as you would a human member of your family	0.51	0.68
Handling subscale (α = 0.77)		
Our dog/s is/are accustomed to being touched	0.78	0.64
Our dog/s enjoy being petted	0.76	0.67
We often play with our dogs	0.53	0.78
Discarded items (factor loading <.50)		
We enjoy our dogs' companionship		
It is unhealthy to touch dogs		
We never touch our dogs		
Our dog will bite us if we touch it		

produced qualitatively different responses to the other three interviewers, across both subscales and care/physical contact scores. In particular, the slope for interviewer A was not significantly different from zero ($P > 0.07$) in any combination, whereas the mean slope for the remaining three interviewers was significantly positive in all but one case (the exception being the relationship between handling subscale and care score, thus mirroring the results of the non-parametric analysis). The results of the ANCOVA are shown in Table 4.2. Responses obtained from interviews conducted by interviewer A were excluded from the remainder of the analysis (remaining sample size n = 593). Exclusion of these interviews resulted in an improvement of the concurrent validity estimate of the equality subscale (Spearman rank correlation coefficient: care score ρ = 0.18, $P < 0.001$; physical contact score $\rho = 0.22$, $P < 0.001$).

4.3.3 Attitude scores

Actual scores obtained from the survey covered the full range of possible scores (5-25 for equality subscale and 3-15 for handling subscale). The frequency distribution of scores for both sub-scales were strongly skewed towards more favourable attitudes (measure of skew for equality subscale = -2.39 SE±0.08 and handling subscale = -1.23 SE±0.09, where skew = 0 represents a normal distribution; two-tailed t-test, $P < 0.001$). Univariable analysis using non-parametric statistics revealed a significant association between the sex of the respondent and the score of both the equality subscale (Wilcoxon rank sum test W = 32789, $P < 0.001$) and the handling subscale (Wilcoxon rank sum test W = 35152, $P = 0.04$), with males displaying a more positive attitude than females in

Table 4.2. Results of an analysis of covariance examining the effect of interviewer (A,B,C & D) on the relationship (intercept and slope) between care/physical contact scores and attitude subscales. P-values are t-test p-values of the difference in parameter estimates between interviewer A and BCD combined

Outcome variable (subscale)	Independent variable	Intercept			Slope		
		A	BCD	*P*-value	A	BCD	*P*-value
Equality	Care score	21.0	20.6	0.001	-0.06	0.23	<0.001
	Contact score	21.1	20.7	0.006	-0.16	0.30	<0.001
Handling	Care score	12.3	10.2	<0.001	-0.02	0.15	0.17
	Contact score	12.3	10.4	<0.001	0.04	0.64	<0.001

both cases, although effect sizes were small (Cohen's *d*: equality subscale $d = 0.31$, handling subscale $d = 0.17$). A significant association was also found between the religion of the respondent and equality subscale score (Wilcoxon rank sum test W = 32789, $P < 0.001$), with Muslim respondents having a higher mean score that Christian respondents (Cohen's $d = 0.18$). No association was found between either subscale and the age, level of education or socio-economic index (as measured by household asset index, see Gwatkin *et al.*, 2000 and Filmer & Pritchett, 2001) of the respondent ($P > 0.17$) or between handling subscale score and religion ($P = 0.41$). Overall there was no association between either subscale score and presentation of eligible dogs for rabies vaccination by the household ($P > 0.17$); however, when this analysis was restricted to only those respondents who were also the heads of their households, a significant relationship was found between equality subscale score and vaccination (Wilcoxon rank sum test W = 31618, $P = 0.02$).

4.4 Discussion

The derived subscales showed acceptable levels of internal reliability and a degree of concurrent validity, with respondents' scores being in particular correlated to self-reported levels of physical interaction with household dogs. The weak association between equality subscale scores and the level of care provided for household dogs is consistent with results obtained by Shore *et al.* (2005), who found that even pet owners reporting low attachment provide beneficial care and attention to their pets. The owner behaviours recorded in our study which went to make up the level of care scores comprised behaviours which Shore *et al.* (2005) categorized as either 'essential' or 'standard' (i.e. providing for little more than the basic physical needs of the animal), at which level they found minimal differences in frequency of behaviour based on the reported degree of attachment.

The robustness of the measure of the concurrent validity of the derived subscales is in turn related to the validity of self-reported behaviour as a measure of the true behaviour of respondents towards their household dogs. Assessments of behaviour which rely on self-reporting may be subject to strong biases, particularly social desirability (an attempt by the respondent to portray him/herself in a more favourable light). Direct observation of participant behaviour might produce a more reliable estimate of concurrent validity, but would need to be done in a manner which would not elicit the same social desirability bias as self-reporting – it is difficult to envisage how this might be achieved.

An assessment of the content validity (the degree to which a specific set of items reflects a content domain) is a subjective exercise. According to DeVellis (2003), "in theory, a scale has content validity when its items are a randomly chosen subset of the universe of appropriate items." In the absence of such a 'sampling frame' of relevant items, content validity is dependent on the methods used to construct the scale. It could be argued that the content validity of the derived subscales in the current study could have been improved by considering a larger initial pool of items, and/or by having items reviewed by experts for relevance to the domain of interest or suggestions of content areas that had been omitted.

In order to have predictive validity, an item scale is required to have an empirical association with some 'gold standard' criterion. The positive association between the equality subscale score of household heads and vaccination of eligible dogs at a central point is a measure of the predictive validity of the subscale. Presentation of dogs for vaccination against rabies at a central point can conceivably be considered a 'gold standard' against which the validity of a scale assessing attitudes towards dogs could be assessed, although other unrelated attitudes (e.g. towards the public health risks posed by unvaccinated dogs, or a sense of individual responsibility towards society) may play a role.

Decisions concerning household matters, including domestic animals, tend to be taken by the identified head of the household, although resulting actions may be carried out by other household members. This may explain the lack of an association between individual respondents' attitude scores and dog vaccination, and highlights the need to identify relevant household occupants, both when collecting questionnaire data and when implementing education and awareness campaigns based on such data (Stallones *et al.*, 1990). The lack of an association between vaccination and attitudes towards handling dogs (and the correlated level of physical handling of household dogs) suggests that these factors are not impediments to attaining a reasonable rabies vaccination coverage among the owned dog population in Tanzania.

Given the common assumption that dog ownership in sub-Saharan Africa is primarily motivated by utilitarian rather than affective concerns, the strong bias towards positive attitudes found in this study may seem surprising. However, it should be pointed out that the derived attitude scale assessed only one dimension (affect) of Serpell's postulated two-dimensional model of human attitudes to animals (Serpell 2004), and this only among dog-owning households. While the current findings suggest a more complex (and positive) relationship between people and dogs in Tanzania than may have been assumed, further research is needed to ascertain people's perceptions of dogs' instrumental value using a scale instrument capable of capturing this extra dimension.

The selection of dog-owning households for the study represents a convenience sample based on the identification of all dog-owning households within the site known to members of the local community, appointed by community leaders to act as guides for the vaccination teams. This sample has been shown to be biased in the direction of male-led households occupying lower socio-economic strata when compared to the characteristics of households identified as dog-owning during a simple random cross-sectional sample. This likely reflects the background of the guides themselves, and the lack of engagement of wealthier households with the wider community. This bias should be kept in mind when interpreting the results of this study.

The current weight of evidence shows that Interviewer A produced significantly different results in the validation of the study against concurrent criteria, when compared to Interviewers B, C and D, in both individual and combined comparisons. The results of the individual analyses are not shown as the information is incorporated in the combination of B, C and D into a single factor level. Further exploration of interviewer effect could have been done with, for example, the construction of a generalised linear mixed model with appropriate error structure and with ward as a random effect. The significance of the interviewer variable on the model, and on the coefficients of the other parameters could have been evaluated in such a model. This complex approach was not followed, not only due to a lack of expertise on the part of the author, but also because the nature of the data (particularly the sample bias discussed on page 110) does not seem to warrant complex analyses. There was no *a priori* reason to assume that results of different interviewers would differ significantly (other than as a result of an interviewer effect *per se*): all interviewers worked in all 12 study sites, and (although not done strictly randomly) households were assigned on an *ad ho*c basis to interviewers, with no prior knowledge of the study area. It is conceivable, although unlikely, that the households interviewed by A differed systematically across sites from those interviewed by the other 3.This possibility could be assessed by testing for differences in the characteristics of households interviewed by each of the four individuals. While care should be taken to avoid over-interpretation of the results of the ANCOVA (given the non-parametric structure of the data, and the biased sample from which the data were collected), the effect of interviewer A on the quality of the relationship between the attitude subscales and behaviour scores, and thus on the assessment of concurrent validity, is appreciable. 'Interviewer effect' is the component of error (i.e. the difference between the true value of a respondent and the value reported by the interviewer) that is due to a systematic bias on the part of the interviewer (Kish, 1962). This effect may be seen if interviewers deviate systematically from standardized procedures, through for example idiosyncratic interpretation of questions, or if particular interviewer characteristics elicit certain behavioural patterns within respondents, such as social-desirability mechanisms (which may be more pervasive in face-to-face interviews: Leggett *et al.*, 2003). Several authors have found that attitude items are more susceptible to interviewer effects than factual items (O'Muircheartaigh, 1976; Collins & Butcher, 1982), while others (Kish, 1962) have postulated that interviewer effects are more likely to occur if respondents are forced to answer questions about unfamiliar topics or in an unfamiliar format, as may have been the case in the current study. The analysis of interviewer effect presented here is useful to make future users of this and other scales aware of the potential for bias introduced by this phenomenon. Thorough training and rigorous, ongoing quality control, along with careful experimental design that allows for an evaluation of interviewer effect (e.g. ensuring that interviewer and site are not inextricably confounded), should be sufficient to prevent loss of data in other settings.

In this study, we found that male respondents have a more positive attitude towards dogs than females. In a recent review of gender differences in human-animal interactions, Herzog (2007) reported that most studies measuring attachment to pets found relatively small, if any, differences between the sexes. Among the studies reporting a statistically significant association between respondents' gender and attachment to companion animals, effect sizes (as measured using Cohen's *d*) averaged only 0.22. This is indicative of a small male/female difference (Cohen, 1988), and is similar in magnitude to the effect sizes obtained in the current study (0.17 and 0.31). One qualitative difference between the results of this and previous studies is the direction of the association: the majority of previous studies have shown that it is females who generally exhibit a greater degree of attachment to companion animals (Selby & Rhoades, 1981; Miura *et al.*, 2000) although, as Herzog (2007) points out, this is dependent on a number of additional factors including the age of the respondents and the species of companion animal concerned. Socio-cultural factors undoubtedly also play a role: in an exception to the general trend, Al-Fayez *et al.* (2003) reported that gender differences in pet attachment patterns were reversed among adults in Kuwait. The more positive attitudes of male respondents towards dogs in the current study adds weight to the findings of a recent study of dog ownership patterns in Tanzania, which showed that dog ownership was significantly associated with male-led households (Knobel *et al.*, 2008).

The effect seen in this study of respondents' religion on perception of dogs as equals, is somewhat surprising as the direction of the association is contrary to expectations, i.e. Muslim respondents were hypothesized to demonstrate a less positive attitude towards dogs than their Christian counterparts, on the basis of traditional interpretations of Islam which endorse the notion of dogs as 'unclean' animals (Foltz, 2005). Knobel *et al.* (2008) found that Muslim households in Tanzania were significantly less likely to own dogs, but that when livestock-owning households were examined, religion no longer predicted dog ownership. While this finding suggests that utilitarian needs (dogs are frequently used to guard livestock) may override considerations based on religious interpretation, the results of the current study also point towards the existence of an 'affective' response among dog owners (Serpell 2004), regardless of religious persuasion. Although Al-Fayez *et al.* (2003) did find that scores on the Pet Attitude Scale (Templer *et al.*, 1981) among respondents in Kuwait (a predominantly Muslim country) were on average lower than those of American respondents, there was a considerable degree of overlap. Those authors point out that Islamic teachings regarding the rights of animals are both elaborate and specific (see Foltz, 2005 for a detailed discussion), and may not warrant simplistic conclusions. A measure of the religiosity of respondents, rather than merely religious category, may provide more insight into this relationship (Hill & Hood 1999). Bowd & Bowd (1989) and Heleski *et al.* (2004) found a negative correlation between religiosity and positive attitudes towards animal treatment. Further studies incorporating non-dog-owners are needed to explore the influence of individual and cultural modifiers on attitudes towards dogs, and to explore the position occupied by household dogs in Tanzania within the two-dimensional space described by the affect and utility dimensions, as proposed by Serpell (2004).

Previous studies report conflicting findings on the associations between pet attachment and the age, level of education and socio-economic status of respondents. Lago *et al.* (1988) and Johnson *et al.* (1992) found that respondents with less education and a lower annual income reported stronger attachment to pets, while in a multivariable model Stallones *et al.* (1990) found no relationship between level of education and pet attachment. These authors also found no relationship with the age of respondents, as did Lagos *et al.* (1988), while Johnson *et al.* (1992) reported that older respondents were more highly attached to their favourite pets. The high degree of collinearity between these variables (Westgarth *et al.*, 2007; Knobel *et al.*, 2008), and the influence of other factors such as the length of time of pet ownership (Bagley & Gonsman, 2005), suggest that the results of univariable analyses should serve only as a preliminary basis for more complex multivariable studies.

4.5 Conclusion

The derived item scale appears to be an accurate and valid measure of respondents' attitudes towards household dogs, and is the first such instrument to be applied in a developing country setting. It provides a basis for further studies into the factors influencing dog-keeping and the ecology and welfare of owned dogs in these regions, and highlights the need for veterinary and public health officials to take account of people's attitudes towards dogs when planning rabies prevention and control programmes.

The following two chapters attempt to address similar questions related to dog ownership and attitudes towards dogs as the previous two chapters, expanding on and applying the methodologies developed in those earlier chapters to a new setting in south Asia, namely the city of Colombo in Sri Lanka.

5 CHAPTER 5: OWNERSHIP AND WELFARE OF AN URBAN DOG POPULATION IN COLOMBO, SRI LANKA

5.1 Introduction

The world's urban population is projected to grow by 2 billion before 2030 (United Nations Population Division, 2003), and more than 90% of this growth will take place in the least developed countries (United Nations Population Division, 2002). The year 2007 marked the first time in human history that the majority of the planet's human population lived in cities. The rapid urbanization of human populations is accompanied by a parallel increase in the urban numbers of an animal species almost ubiquitously associated with people: the domestic dog. Densities of up to 3,000 dogs km^{-2} have been recorded in some urban centres (Wandeler *et al.*, 1993). Such high concentrations of dogs and humans in close proximity has potentially detrimental consequences to the health and welfare of both populations. Domestic dogs inflict bites and transmit infectious diseases to people, while they in turn are killed in attempts to reduce their numbers or bring disease outbreaks under control. At high densities dog populations suffer significant mortality from pathogens including canine parvovirus, canine distemper virus, helminths and mites. Limited access to resources leads to malnutrition and neonatal mortality. A detailed understanding of the ecology of urban dog populations, particularly the factors – both anthropogenic and non-anthropogenic – that regulate dog numbers, is crucial to any attempt to mitigate the public health consequences and simultaneously improve the welfare status of urban dog populations.

The current study focused on the owned dog population in a large urban centre in Sri Lanka. This country has some of the highest recorded densities of domestic dogs

(Wandeler *et al.*, 1993). Previous studies have found significant numbers of poorly supervised or unowned dogs, sustained by abundant available resources (Wandeler *et al.*, 1993; Matter *et al.*, 2000). Dogs are the main reservoir and vector of rabies on the island: over 96% of reported rabies cases in animals occur in dogs, and 95% of human rabies deaths are due to bites from rabid dogs (Harischandra, 1996). A national programme for the elimination of rabies in Sri Lanka was adopted in the 1980s, focussing on the vaccination of dogs to achieve a coverage of 75-80%, the elimination of stray dogs, and provision of post-exposure prophylaxis for bite victims of suspected rabid animals (Harischandra, 1996). Despite these control efforts, an increase in the number of human and animal rabies cases has occurred since 1994. Concern for the welfare of the stray dog population, and the failure of stray dog removal strategies to control endemic canine rabies, have prompted public health and animal welfare agencies to investigate alternative humane methods of dog population control. In 2007 the World Society for the Protection of Animals (WSPA) and the Blue Paw Trust (BPT), together with the Colombo Municipal Council (CMC), launched a comprehensive humane dog population and urban rabies control programme in Colombo. As part of the larger objectives of this programme, which included an investigation into the demographics and determinants of numbers of roaming dog, the aims of the current study were to characterise the demographics and welfare status of the owned dog population and to examine the factors associated with dog ownership amongst the inhabitants of Colombo.

5.2 Methods

5.2.1 Study design

The study was conducted during June 2007, in the Colombo Municipal Council (CMC) area of Colombo City, Sri Lanka. According to the 2001 Census (Department of Census & Statistics, 2001), the CMC had a population of 647,000 people in 115,000 households. The CMC is divided into 47 wards. A two-stage random sampling method was used to select households for the survey. Seven wards were systematically selected from within the CMC area by selecting every 6th ward starting from a randomly-generated number, and within these wards, a systematic random survey of the number of owned dogs was made of every 10th household encountered. The definition of a household was derived from the 2001 census. Briefly, this defines a household on the basis of people who live together and have common arrangements for the provision of food. Detailed street maps were used to ensure that the entire ward area was covered. A questionnaire was administered by one of a team of trained interviewers to every eligible dog-owning household (DOHH), and to every 10th non-dog-owning household (NOHH). A household was considered eligible for interview if at least one adult occupant ($\geq$ 16 years) was present and from whom consent was obtained for the interview. Respondents from both DOHHs and NOHHs were asked demographic information about the head of the household, household waste disposal, ownership of dogs in the preceding 12 months, reasons for dog ownership/non-ownership and attitudes towards dogs. The welfare status of owned dogs was assessed through questioning respondents from DOHHs on care provision (food, water, shelter), confinement and veterinary care, and through visual inspection of dogs for body condition score, skin conditions, lameness and wounds. Body condition score (BCS) was based on visual assessment of four body areas (Figure 5.1): backbone, ribs, abdominal tuck and waist (viewed from above). An objective scoring system was used to assign a score from 1 (cachectic) to 5 (obese) for each dog seen. The response of the dog when called by the respondent was also scored, from 1 (friendly) to 4 (runs away). If a dog was normally chained, the length of the chain relative to the dog's body length was estimated. A crude estimate of the adult annual survival rate was obtained by comparing the number of adult dogs (>6 months) reported to have been owned 12 months previously with the number of currently owned dogs over 18 months old. This method allows for the small number of adult dogs that were given away or acquired during the 12-month period.

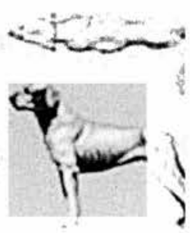
5.2.2 Predictors of dog ownership

The association between dog ownership and various household factors was explored using a multivariable logistic regression model. Six household variables were evaluated: the sex (male/female), age category (16-35 years/36-55 years/≥ 56 years) and religion (Buddhist/Christian/Hindu/Muslim) of the head of the household, the number of household occupants (1-3 occupants/4-6 occupants/≥ 7 occupants), the housing structure (single/attached/flat/row) and the attitude of the respondent to dogs. The latter was quantified as the responses to a series of 18 standardised item statements dealing with both owned and unowned dogs (Chapter 6, this volume). Each item consisted of a single statement, to which respondents could express varying degrees of agreement or disagreement (along a 7-point Likert scale). Each item was scored from 1-7, such that a

Body condition score is based on 4 main body areas, check each one in turn to assess score:

→ **Backbone** – if clearly visible score 1, if not visible check ribs
→ **Ribs** – if clearly visible score 2, if not visible check abdominal tuck
→ **Abdominal tuck** – if clearly visible score 3, if just visible score 4, if not at all visible score 5, then double check by viewing waist from above
→ **Waist from above** – if clearly visible score 3, if just visible score 4, if no waist score 5

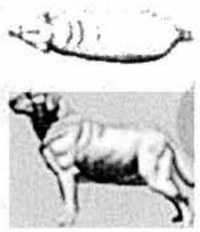
1) **EMACIATED** - Ribs, backbone, pelvic bones VISIBLE FROM A DISTANCE. No body fat.



2) **THIN** - Ribs easily palpated and visible on close inspection. SOME BODY FAT PRESENT. Abdominal tuck evident. Waist visible from above

3) **IDEAL** - Ribs palpable but NOT VISIBLE even on close inspection. Waist easily visible from above. Fat readily palpable over kidneys.

4) **OVERWEIGHT** - Ribs palpable with excess fat present. Waist barely visible from above. Abdominal tuck apparent.



5) **OBESE** - Ribs barely palpable. Waist absent. Large

Figure 5.1. Basis of the objective 5-point body condition scoring system

higher score reflects a more positive attitude towards dogs, and the score of all items was then summed for each respondent. Scores ranged from 18-122. The shape of the relationship between attitude score and the log odds of dog ownership was assessed by visual inspection of a smoothed scatterplot (using Friedman's super smoother). As there was no obvious evidence of non-linearity, attitude score was entered into the model as a continuous variable. A multivariable logistic regression model of dog ownership was constructed by backward stepwise selection of variables. Variables were retained in the model if the likelihood-ratio test p values were <0.05. The Wald test p-value was used when comparing categories with the reference category. The fit of the final multivariable model was assessed using the Hosmer-Lemeshow goodness-of-fit test, and its predictive ability determined by generating a receiver operator characteristic (ROC) curve (Hosmer & Lemeshow, 2000). Statistical analysis was done using R version 2.4.1 (The R Foundation for Statistical Computing, http://www.r-project.org).

5.3 Results

5.3.1 Dog ownership

A total of 1,841 households were surveyed across the seven wards. When compared to the number of households in each ward recorded in the 2001 census, the proportion surveyed ranged from 7.0% to 8.9% (average 7.5%). Information on dog ownership was obtained from 1,823 households, of which 243 (13.3%) owned one or more dogs. The dog-to-human ratio was 1:32. Figure 5.2 shows the distribution of dogs per DOHH. The mean number of dogs per dog-owning household (DOHH) was 1.34 (95% CI 1.32-1.35). The questionnaire was administered to 195 DOHH. Of the non-dog-owning households (NOHH), 149 were selected for interview. There was a high rate of non-response among NOHHs, with 51 interviews not completed due to the absence of an adult member or refusal of consent. Specific reasons for non-response were not recorded. A higher proportion of non-responding NOHHs lived in flats when compared to responding NOHHs (41.2% vs. 26.8%); however, this difference was not significant ($X^2 = 2.56$, d.f. $= 1$, $P = 0.11$). This difference was likely due to the difficulty of accessing blocks of flats as permission was often not granted by security personnel in the lobby. Among 94 non-dog owning households who gave a reason for not owning a dog, 35 (37%) gave their main reason as not having enough space to keep a dog; 29 (31%) as not liking dogs; 23 (24%) as being discouraged by their religion/culture; 4 (4%) as not feeling the need to keep a dog; 2 (2%) as not having time to look after a dog; while 1 (1%) household said they were currently looking for a new dog.

5.3.2 Dog demographics and welfare

Demographic and welfare information was obtained for 259 dogs in 187 households. The crude estimate for adult annual survival was 0.804. The average annual number of litters per (unsterilised) female over 12 months of age was estimated at 0.13. The sex ratio was 1.7 males per female. Most dogs (67%) were kept as pets, with the remainder kept as guard dogs. The welfare status of the owned dog population was on the whole good: 73% of dogs had a body condition score of 3 or more, although 17% had some evidence of skin conditions (typically mange). There was little evidence of fresh wounds (5%) or lameness (1%) in the population. Vaccination coverage against rabies is very high among the owned dog populations, with 83% of the sampled population reported to have been vaccinated within the 12 months preceding the study (although this was not verified by inspection of certificates). Many dogs (44%) are dewormed regularly, with only 17% of dogs never dewormed. Three-quarters of the dogs sampled are permanently confined, with the majority of these confined to a compound with access to shelter (66%); 21% of permanently-confined dogs are kept in kennels, and the remainder are tied or chained, all with access to shelter. Average chain length is 2x dog body length. Almost all dogs evaluated (94%) displayed a friendly response when approached by the respondent.

5.3.3 Predictors of dog ownership

Households were classified as DOHH (n = 195) or NOHH (n = 98). The results of the multivariable model show that the age and religion of the head of the household, the type of housing, and the attitude of the respondent towards dogs are all significantly associated with dog ownership. Households headed by people within the age category 16-35 years were significantly less likely to own dogs than households headed by middle-aged individuals 36-55 years old (OR 0.19 95% CI 0.06-0.55). Likelihood of dog ownership did not differ significantly between older ($\geq$ 56 years) and middle-aged household heads (OR 0.65 CI 0.27-1.57). The religion of the head of the household was strongly associated with dog ownership. Compared to Buddhist households, the odds of dog ownership were significantly lower in Hindu (OR 0.33 95% CI 0.14-0.80) and

Muslim households (OR 0.03 95% CI 0.00-0.25), but not different in Christian households (OR 1.29 95% CI 0.43-3.83). Compared to single houses, the odds of dog ownership were lower in both attached houses (OR 0.29 95% CI 0.11-0.75) and in flats (OR 0.26 95% CI 0.09-0.71). Increasing attitude score was associated with increased odds of dog ownership (OR per extra point 1.08 95% CI 1.05-1.11). The final multivariable model appeared to fit the data well (Hosmer-Lemeshow goodness-of-fit test statistic = 5.32, d.f. = 8, P = 0.72). The ROC curve is shown in Figure 5.3. The area under the curve was 0.90, indicating the model has good predictive ability.

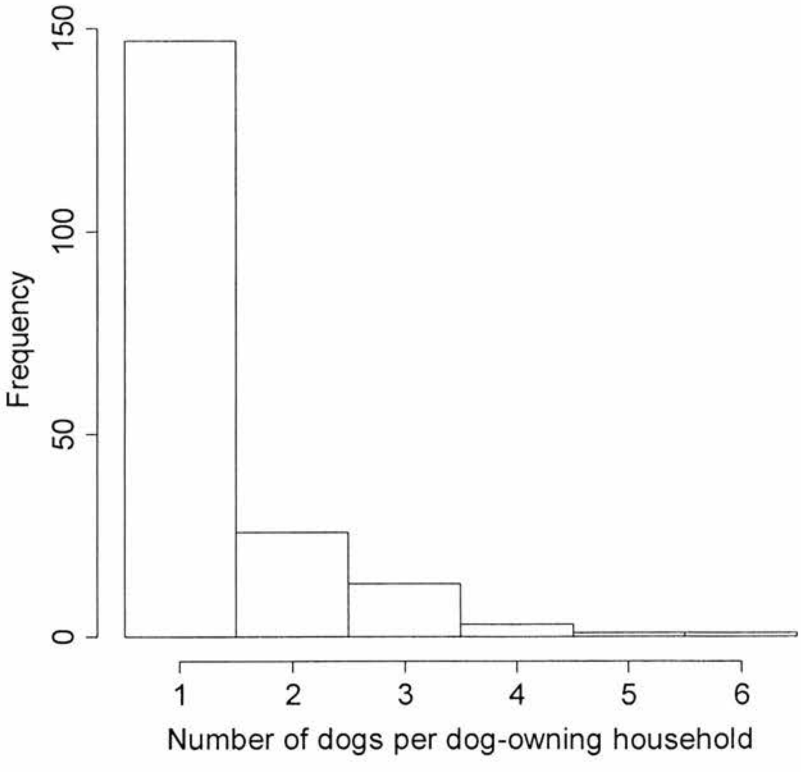


Figure 5.2. The distribution of dogs per dog-owning household (DOHH) in the Colombo Municipal Council, Sri Lanka

Table 5.1. Univariable analysis of factors associated with dog ownership in Colombo

Variable	Total (n = 293)	DOHH (%) (n = 195)	NOHH (%) (n = 98)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Sex of head of household								
Female	60	40 (21)	20 (21)				1(REF)	
Male	225	147 (79)	78 (79)	0.06	0.308	**0.85**	1.06	0.58-1.94
Missing	8	8	0					
Age of head of household (years)						**0.004**		
36-55	130	90 (53)	40 (46)				1(REF)	
16-35	40	17 (10)	23 (26)	-1.11	0.372	0.003	0.33	0.16-0.68
56+	86	62 (37)	24 (28)	0.14	0.306	0.65	1.15	0.63-2.09
Missing	37	26	11					
Religion of head of household						**<0.001**		
Buddhist	107	84 (45)	23 (24)				1(REF)	
Christian	78	64 (34)	14 (15)	0.22	0.377	0.55	1.25	0.60-2.62
Hindu	70	37 (20)	33 (34)	-1.18	0.336	<0.001	0.31	0.16-0.59
Muslim	27	1 (1)	26 (27)	-4.55	1.045	<0.001	0.01	0.00-0.08
Missing	11	9	2					
Number of household occupants						**0.37**		
4-6	171	116 (64)	55 (60)				1(REF)	
1-3	59	41 (23)	18 (20)	0.08	0.327	0.81	1.08	0.57-2.05
7+	42	24 (13)	18 (20)	-0.46	0.352	0.19	0.63	0.32-1.26
Missing	21	14	7					
Housing structure						**< 0.001**		
Single	173	136 (74)	37 (42)				1(REF)	
Attached	53	28 (15)	25 (28)	-1.19	0.332	<0.001	0.30	0.16-0.58
Flat	47	21 (11)	26 (30)	-1.52	0.347	<0.001	0.22	0.11-0.43
Missing	20	10	10					
Attitude score (per unit)	**293**	195(100)	98 (100)	0.08	0.011	**<0.001**	1.08	1.06-1.11

*Bolded *p*-values are likelihood ratio test *p*-values and unbolded *p*-values are Wald test *p*-values. REF = Reference category.

Table 5.2. Univariable analysis of the effect of different groupings of age on the odds of dog ownership in the study sample, Colombo

	Total (n = 293)	DOHH (%) (n = 195)	NOHH (%) (n = 98)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Age of head of household (years)						**0.004**		
36-55	130	90 (53)	40 (46)				1(REF)	
16-35	40	17 (10)	23 (26)	-1.11	0.372	0.002	0.33	0.16-0.68
56+	86	62 (37)	24 (28)	0.14	0.306	0.65	1.15	0.63-2.09
Missing	37	26	11					
Age of head of household (years)						**0.005**		
33-52	128	88 (52)	40 (46)				1(REF)	
16-32	27	10 (6)	17 (20)	-1.32	0.442	0.003	0.27	0.11-0.64
53+	101	71 (42)	30 (34)	0.07	0.289	0.80	1.08	0.61-1.90
Missing	37	26	11					
Age of head of household (years)						**<0.001**		
36-45	61	36 (21)	25 (29)				1(REF)	
46-55	69	54 (32)	15 (17)	0.92	0.391	0.02	2.50	1.16-5.38
16-25	9	4 (2)	5 (6)	-0.59	0.720	0.41	0.56	0.14-2.28
26-35	31	13 (8)	18 (21)	-0.69	0.448	0.12	0.50	0.21-1.21
56-65	49	41 (24)	8 (9)	1.27	0.466	0.006	3.56	1.43-8.87
66+	37	21 (12)	16 (18)	-0.09	0.422	0.83	0.91	0.40-2.08
Missing	37	26	11					

*Bolded *p*-values are likelihood ratio test *p*-values and unbolded *p*-values are Wald test *p*-values. REF = Reference category.

Table 5.3. Univariable analysis of the effect of different groupings of household size on the odds of dog ownership in the study sample, Colombo

Variable	Total (n = 293)	DOHH (%) (n = 195)	NOHH (%) (n = 98)	Coefficient	Standard error	*p*-value*	Odds ratio (OR)	95% confidence interval (CI)
Number of household occupants						**0.37**		
4-6	171	116 (64)	55 (60)				1(REF)	
1-3	59	41 (23)	18 (20)	0.08	0.327	0.81	1.08	0.57-2.05
7+	42	24 (13)	18 (20)	-0.46	0.352	0.19	0.63	0.32-1.26
Missing	21	14	7					
Number of household occupants						**0.37**		
5-6	107	76 (42)	31 (34)				1(REF)	
1-2	25	23 (13)	2 (2)	1.55	0.767	0.04	4.69	1.04-21.11
3-4	98	58 (32)	40 (44)	-0.53	0.296	0.08	0.59	0.33-1.06
7-8	31	19 (10)	12 (13)	-0.44	0.426	0.30	0.65	0.28-1.49
9+	11	5 (3)	6 (7)	-1.08	0.642	0.09	0.34	0.10-1.20
Missing	21	14	7					

Table 5.4. Multivariable logistic regression model of factors associated with dog ownership in Colombo, Sri Lanka (n = 293)

Variable	Coefficient	Standard error	p-value*	Odds ratio (OR)	95% confidence interval
Age category of head of household			**0.007**		
36 - 55 years				1 (REF)	
16 - 35 years	-1.67	0.544	0.002	0.19	0.06-0.55
≥ 56 years	-0.43	0.451	0.34	0.65	0.27-1.57
Religion of head of household			**<0.001**		
Buddhist				1 (REF)	
Christian	0.25	0.556	0.65	1.29	0.43-3.83
Hindu	-1.10	0.451	0.01	0.33	0.14-0.80
Muslim	-3.62	1.131	0.001	0.03	0.00-0.25
Type of housing			**0.005**		
Single (unattached)				1 (REF)	
Attached	-1.23	0.482	0.01	0.29	0.11-0.75
Flat	-1.36	0.520	0.009	0.26	0.09-0.71
Attitude score (per unit)	0.076	0.015	**< 0.001**	1.08	1.05-1.11
Intercept	-3.50	1.16			

*Bolded p-values are likelihood ratio test p-values and unbolded p-values are Wald test p-values. REF = Reference category

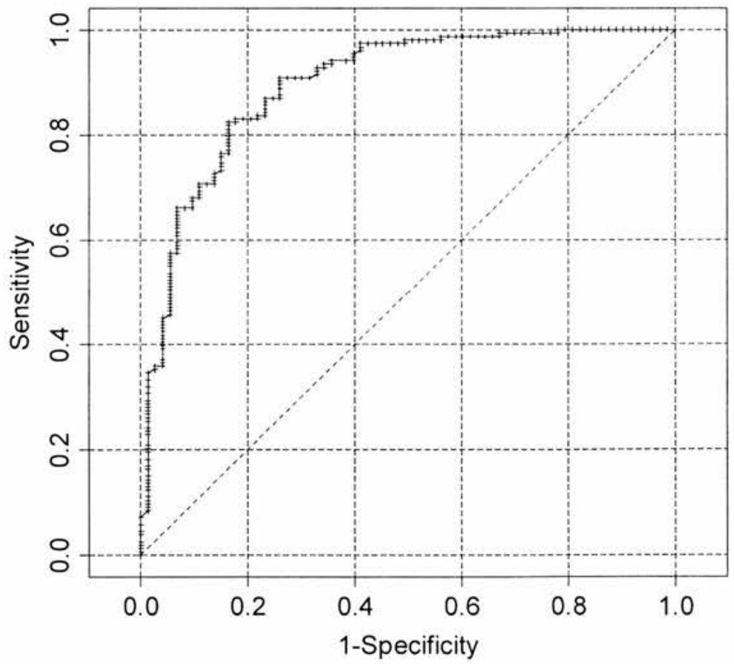


Figure 5.3. Receiver-operator characteristic (ROC) curve for the fitted model. The area under the curve is 0.90.

5.4 Discussion

The owned dog-to-human ratio of 1:32 found in this study is lower than the composite figure for a number of urban Asian dog populations (95% CI 4.8 -10.1, Knobel *et al.*, 2005), and the figure found for a peri-urban population in Mirigami, 45km north-east of Colombo (1:6, Matter *et al.*, 2000). The ratio is however similar to that seen in combined urban African settings (95% CI 12.5 – 37.1, Knobel *et al.*, 2005), and in a later study in Tanzania (95% CI for three urban coastal sites: 23.9-31.1, Knobel *et al.*, 2008). The proportion of dog-owning households found in this study (13.3%) is also broadly similar to that found in other urban areas (13.3% in Iringa, Tanzania (Gsell, 2006); 95% CI for six urban sites in Tanzania: 10.9% – 12.1%, Knobel *et al.*, 2008) but lower than reported national estimates from industrialised countries including the United States (36.1%, Wise *et al.*, 2002), Japan (24.2%, Inaba, 1998), Taiwan (22.9%, Hsu *et al.*, 2003), and Sweden (15.5%, Egenvall *et al.*, 1999). .

The overall welfare status of the owned dog population was good, and this is supported by the high estimated adult annual survival. The strong bias towards male dogs in the owned population has been noted in other studies in Sri Lanka (Wandeler *et al.*, 1993; Matter *et al.*, 2000). This is most likely anthropogenically-mediated, through increased mortality of female dogs (directly or through neglect) or enforced emigration of female dogs from the owned dog population ('dumping' female puppies). The few studies that have examined the sex-ratio among unowned dogs have found this to be closer to parity, although still somewhat biased towards males (Matter *et al.*, 2000; World Society ofr the

Protection of Animals/Blue Paw Trust, 2007), possibly suggesting a high mortality rate among 'dumped' females. In informal interviews, people expressed a preference for male dogs, primarily to avoid difficulties associated with a reproductively-active female (unwanted litters, and disturbance when on heat). In the current study 23% of owned females were sterilised, and almost half (44.4%) of the owners of unsterilised females were willing to get their animals sterilised. This indicates that uptake of a humane dog population control programme focused on the surgical sterilisation of owned females would be good. Potential barriers to uptake include specific cultural beliefs among some Buddhist owners of the right of female animals to breed freely. Information on the impact of such a population control programme on the demography and welfare of both the owned and unowned segments of the dog population is urgently needed.

Households headed by young (16-35 years old) members were significantly less likely to own dogs than those headed by middle-aged or older individuals. Similar findings have been reported in a number of studies in western countries (Wise & Kushman, 1984; Troutman, 1988; Teclaw *et al.*, 1992; Leslie *et al.*, 1994; Westgarth *et al.*, 2007). In most cases this was shown to relate to the presence and age of children within the household, with families with no or young (<6 years old) children less likely to own dogs. Socio-economic factors may also play a role – younger people are more likely to live in housing where space is a constraint on keeping dogs. Dog ownership was more likely in single (i.e. unattached) houses when compared to both flats and attached houses. These findings, together with the primary reason for non-dog ownership being space constraints, suggest that this may be a critical limiting factor in determining the 'carrying capacity' of the owned domestic dog population, rather than demand for dogs *per se*.

The strong association between the religion of the head of the household and dog ownership is interesting, and the Christian/Muslim differential mirrors the findings from Tanzania (Chapter 4, this volume). This relationship, found within two very different cultural contexts, suggests an effect of religion *per se,* over and above associated cultural determinants. However, it is recognised that religions are not homogenous, and future studies on this topic would benefit from a more in-depth examination of religious and cultural determinants (e.g. religiosity, ethnic group, language, etc) of perceptions and behaviour towards dogs.

A limitation of this study is the potential bias introduced by the survey method. No sampling frame of households was available; hence a systematic survey method of every 10th household was adopted. The shortfall between the observed (7.5%) and expected (10%) proportion of households in the survey is likely due to multiple-household dwellings from whom a respondent was not available. These may have been assumed by interviewers to contain only a single household. A further limitation is the high rate (34%) of non-response among NOHHs. Despite these limitations, the systematic survey method remains a practical and useful tool for estimating numbers of owned dogs.

5.5 Conclusions

Identification of the household predictors of dog ownership, together with the description of the welfare status of owned dogs presented in this paper, will enable welfare agencies to effectively target education and awareness campaigns, and promote delivery of owned female dogs for sterilisation as part of a comprehensive humane dog population management programme. Characterisation of the demographics of owned dogs and their associated households is also a first step to understanding some of the anthropogenic drivers of urban dog population dynamics.

6 CHAPTER 6: ATTITUDES TOWARDS DOMESTIC DOGS AMONG INHABITANTS OF COLOMBO, SRI LANKA: IMPLICATIONS FOR A HUMANE DOG POPULATION MANAGEMENT PROGRAMME

6.1 Introduction

Domestic dogs and humans co-exist in a complex inter-relationship across almost the entire globe. Dogs' dependency on humans ranges along a continuum (World Health Organization, 1988), from one extreme where all of their essential needs are supplied intentionally, through to semi-dependency, to a situation where dogs receive none of their essential resources intentionally from humans. In many parts of the world, particularly in developing countries, sub-populations of dogs at different points along this continuum co-exist side-by-side with one another and with the human population. In any given dog population there are thus dynamic forces, both anthropogenic and non-anthropogenic, that interact to regulate the population. Understanding the nature and balance of these forces in different environments may be important to public health officials, veterinarians and animal welfare agencies, seeking to control infectious diseases such as rabies and to improve the health and welfare of dog populations.

Anthropogenic drivers of dog population dynamics, such as ownership, intentional resource provisioning, movement restriction and reproductive control, are expressed as human behaviours which are in turn influenced by underlying attitudes towards dogs. Such attitudes are themselves affected by particular socio-cultural contexts or individual attributes. For example, within the framework of Serpell's (2004) postulated two-dimensional model of human attitudes to animals, women tend to show stronger affective and weaker utility orientations than men (Kellert & Berry, 1980; Bowd & Bowd, 1989; Driscoll, 1992; Herzog, 2007), and higher levels of education are associated with more positive affect and less extreme utility orientations, as is urban versus rural residence (Kellert & Berry, 1980; Bjerke *et al.*, 1998; Reading *et al.*, 1999). It should be noted though that all these studies have been conducted in developed countries. No attempt at describing the ecology of dog populations in areas of human habitation can be complete without understanding the attitudes of the human populace towards dogs, and how these attitudes are expressed as behaviours that affect the demographics and welfare of the dog population. A necessary first step in understanding attitudes is to quantify them using measurement tools that are accurate and valid within the particular socio-cultural context.

The current study focused on the owned dog population in a large urban centre in Sri Lanka. This country has some of the highest recorded densities of domestic dogs (Wandeler *et al.*, 1993). Previous studies have found significant numbers of poorly supervised or unowned dogs, sustained by abundant available resources (Wandeler *et al.*, 1993; Matter *et al.*, 2000). In urban centres, these sub-populations co-exist with an unknown number of owned dogs. It is hypothesised that the owned dog population may form a pool from which the unowned 'street' dog population is replenished, through enforced emigration of particularly female dogs (i.e. 'dumping' of unwanted female puppies by owners). The high fecundity in the owned dog population may therefore compensate for the lower reproductive success and higher mortality among the unowned dog population. In 2007 the World Society for the Protection of Animals (WSPA) and the Blue Paw Trust (BPT), together with the Colombo Municipal Council (CMC), launched a comprehensive humane dog population management programme in Colombo, with a focus on the voluntary sterilization of female dogs by owners and improvement of responsible ownership. As part of the larger objectives of this programme, the aims of the current study were to describe and quantify baseline attitudes amongst both dog-owners and non-owners towards dogs, to explore possible predictors of these attitudes, and to determine if peoples' attitudes are associated with the welfare status of the owned dog population. These aims were to be achieved through the development of an item scale capable of reliably quantifying respondents' attitudes towards dogs.

6.2 Methods

6.2.1 Study design

The study was conducted during June 2007 in the Colombo Municipal Council (CMC) area of Colombo City, Sri Lanka. A stratified random sampling method was used to select households for the survey. Seven wards were systematically selected from the 47 wards within the CMC area by selecting every 6th ward starting from a randomly-generated number, and within these wards, a systematic random survey of the number of owned dogs was made of every 10th household encountered. The definition of a household was derived from the 2001 census (Department of Census and Statistics, 2001). Briefly, this defines a household on the basis of people who live together and have common arrangements for the provision of food. Detailed street maps were used to ensure that the entire ward area was covered. A questionnaire was administered by one of a team of trained interviewers to every eligible dog-owning household (DOHH), and to every 10th non-dog-owning household (NOHH). A household was considered eligible for interview if at least one adult occupant ($\geq$ 16 years) was present and from whom consent was obtained for the interview. The questionnaire contained sections on household demographics, dog ownership, care provision and welfare status of any dogs present, and attitudes towards dogs. This last section consisted of an 18-item scale, with each item comprising a single statement to which respondents could express varying degrees of agreement or disagreement (along a 7-point Likert scale). Each item was scored from 1-7, such that a higher score reflects a more positive attitude towards dogs, and the score of all 18 items was then summed for each respondent to generate an overall attitude score.

6.2.2 Scale development

The 18 items used in the questionnaire were selected from an initial item pool consisting of 85 7-point Likert scale items, assembled using existing sources (compiled in Anderson, 2007) and *de novo* items developed after informal interviews with community leaders, and dog-owning and non-owning members of the community. This was narrowed down by project investigators to a pool of 41 items that were felt to be culturally relevant to Colombo. A further six items were discarded after pilot testing revealed ambiguities in respondents' interpretations of the statements. The remaining 35 items were further piloted among a small number of respondents (n = 16) in a CMC ward not selected for the main study. Each item's performance was then evaluated on the basis of its corrected item-scale correlation (the correlation between the item in question and all the scale items). The items with a corrected correlation co-efficient greater than 0.5 were retained for use in the main study (Table 6.1).

The scale development procedure presented here was an attempt to improve on the method described in Chapter 4, and ultimately improve on the performance of the derived scale. In particular, it was hoped to improve on the content validity (see DeVellis, 2003, and page 104, this volume) by constructing a larger initial item pool, and evaluating the cultural relevance of individual items through consultation with local experts. A more objective cut-off was also used to determine scale length (items with a corrected correlation co-efficient greater than 0.5).

6.2.3 Statistical analysis

An exploratory factor analysis was conducted on the responses to determine the number of constructs underlying the set of items. The appropriate number of factors was determined by applying the Very Simple Structure (VSS) criterion to the data (Revelle & Rocklin, 1979; complexity = 1). Following varimax rotation, the items loading at more than 50% of the maximum loading on each factor were combined to form possible sub-scales. Cronbach's alpha coefficient (Cronbach, 1951) was computed as a measure of the internal reliability of the item scale. Alpha is an indication of the proportion of variance in the scale score that is attributable to the true 'score' of the underlying construct. Nunnally & Bernstein (1994) suggest a value of 0.70 as a lower acceptable bound for alpha. Parametric, two-tailed tests (t-test for categorical independent variables with two levels; one-way analysis of variance (ANOVA) for categorical independent variables with more than two levels) were used to assess univariable associations between attitude score and independent variables. Six respondent variables were considered: household dog ownership, sex (male/female), age category (16-35 years/36-55 years/≥ 56 years) and religion (Buddhist/Christian/Hindu/Muslim) of the respondent, the number of household occupants (1-3 occupants/4-6 occupants/≥ 7 occupants) and the housing structure (single/attached/flat). The latter five variables were then entered into a multi-way ANOVA, and a final model constructed by backward selection of variables, with retention of those variables with an F-test p value <0.05. The relationship between respondents' attitudes towards dogs and the characteristics of and level of care received by their own household dogs was evaluated among households owning a single dog. Single-dog-owning households (SOHH) were selected to avoid the complication imposed by variation between dogs within the same household. No significant differences in respondents' attitude scores were found between households owning one, two or more than two dogs (p = 0.12). A total of 143 SOHHs were used in the analysis. Dog characteristics which were evaluated include sex (male/female), age category (<12 months/13-24 months/>24 months), function (guard dog/pet) and pedigree (pure-bred/cross-breed/mongrel). The welfare variables assessed are as described in Section 5.3.1. All analyses were performed in R 2.4.1. (The R Foundation for Statistical Computing, http://www.r-project.org).

As the derived item scale is composed of individual Likert items that are clearly ordinal, the use of statistical procedures assuming interval level data (e.g. t-tests, ANOVA and Cronbach's alpha) for the analysis of the summed scale requires some justification. Ordinal data has order, but the intervals between scale points may be uneven, whereas interval data has both order and equal intervals. One of the assumptions of Likert scaling, and indeed scale development in general, is the existence of an underlying continuous variable, the value of which determines the respondents' attitudes. A review of the social science literature reveals a general consensus that responses to several Likert items may be summed and treated as interval data measuring the latent variable, providing that all questions use the same Likert response categories, items have at least five (and preferably seven) response categories, and that the scale is a defendable approximation to an interval scale. This later point was raised by Likert (1932) in his original paper, in which he stressed that the wording of the response levels provide equidistant intervals (positive and negative) from a central, neutral point (Likert used the response options Strongly approve, Approve, Undecided, Disapprove and Strongly disapprove). Some researchers argue that responses to such an item would, at the very least, fall between ordinal- and interval-level measurement, and that to treat it as merely ordinal would lose information (akin to categorising a continuous variable). Parker *et al.* (2002) demonstrated that participants provide a good approximation to interval data in response to questions asked on a 5-point Likert scale, and concluded that parametric statistical methods could reliably be used in the analysis of the responses. Furthermore, in a review of the literature on the topic of ordinal vs. interval data, Jaccard and Wan

(1996) summarize, "Numerous Monte Carlo studies have been undertaken to examine the effects of differing degrees of departure from intervalness on parametric statistics. For many statistical tests, rather severe departures do not seem to affect Type I and Type II errors dramatically." Specific sources showing the robustness of parametric coefficients with respect to ordinal distortion are Labovitz (1970), Kim (1975), Binder (1984) and Zumbo and Zimmerman (1993). It is suggested that any departures from intervalness can be minimised by the use of 7-point scales (as used in this chapter), although given the above discussion any gains may be slight – Dawes (2008) found that data from 5-level and 7-level items showed very similar characteristics in terms of mean, variance, skewness & kurtosis after a simple transformation was applied.

6.3 Results

6.3.1 Scale reliability

A total of 392 households were identified for interview (243 DOHH and 149 NOHH). Of these, 99 were not eligible for interview due to absence of an adult occupant or refusal of consent (48 DOHH and 51 NOHH), and a further 20 respondents did not answer one or more of the attitude questions. Of the final 273 responses, 179 were from

Table 6.1. The 18 items used in the main study, and the results of reliability analysis following administration of the items to a sample of 273 households in Colombo. Cronbach's alpha for the 18-item scale was 0.79

Item	Cronbach's α if item deleted
Having a dog is a waste of money	0.79
I like dogs very much	0.77
Dogs should always be kept outside the house	0.78
I don't like being close to dogs	0.77
Dogs add happiness to people's lives	0.77
People who own dogs should spend time every day playing with them	0.78
If a dog of mine got a skin disease, I would not want it around the house	0.78
If a female dog of mine had a litter of puppies, I would not want to keep them	0.79
A person should treat their dog with as much respect as they would a human member of the family	0.78
A dog is a valuable possession	0.78
Street dogs should be looked after by the community	0.79
The welfare of street dogs is important to me	0.79
People should not feed street dogs	0.79
I like having dogs around on my street	0.79
Dogs should have the same rights and privileges as humans	0.79
Street dogs pose a danger to people	0.79
Street dogs should not be allowed to breed	0.80
It is not acceptable to kill dogs	0.80

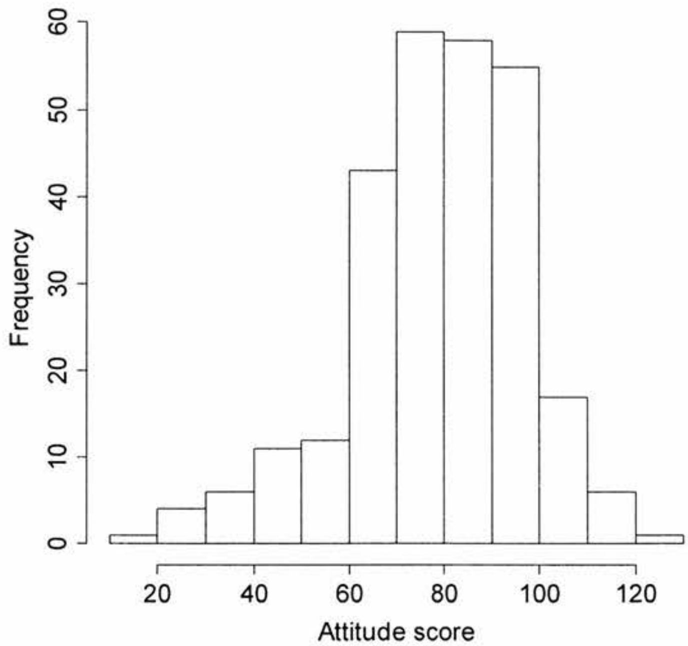


Figure 6.1. A histogram showing the frequency distribution of attitude score among 273 respondents in Colombo

DOHHs and 94 from NOHHs. Figure 6.1. shows the frequency distribution of the final scores. Scores ranged from 18 – 122 (median = 81, mean = 79.1, standard deviation = 8.1). Cronbach's alpha was 0.79, indicating the scale had good reliability. Exploratory factor analysis suggested 3 factors, seemingly related to dogs around the house (7 items), dogs as equals (4 items) and dogs on the street (2 items); however, the reliability of the latter two of these subscales was poor (0.61 & 0.59), thus the remainder of the analyses were done using the entire 18-item scale.

6.3.2 All households

Figures 6.2-6.7 show attitude scores by different categories of respondent. Respondents' attitude scores were found to be strongly related to dog ownership, with respondents from dog-owning households having a significantly more positive attitude towards dogs (two-tailed t-test: DOHH mean = 86.0 NOHH mean = 66.0, t = 9.18, d.f. = 145, $p < 0.001$). Attitudes were also strongly related to the respondents' religion, with Hindus and particularly Muslims having a significantly less positive attitude towards dogs than Buddhists or Christians (one-way ANOVA, $F_{3,265} = 11.5$, $p < 0.001$). The type of housing was also found to be significant, with respondents living in flats less positive towards dogs than those living in single or attached houses (one-way ANOVA, $F_{2,250} = 4.75$, $p = 0.009$). Attitudes were not significantly related to the age and sex of the respondent, nor to the number of occupants in the household ($p > 0.26$). When all variables (excluding dog ownership) were taken into account in a multi-way ANOVA, only the religion of the respondent emerged as a significant predictor of people's attitudes towards dogs following backward selection of variables. Among dog-owning households, none of these variables (including religion, although there was only one Muslim dog-owning household in the sample) were associated with respondents' attitudes.

6.3.3 Dog-owning households

Respondents' attitude scores appear to be associated to some degree with the characteristics and function of their own dog. In particular, respondents who stated that the primary purpose of their dog was to guard the household had significantly lower attitude scores than those who claimed to keep their dog as a pet (two-tail t-test: pet mean = 86.6, guard mean = 81.2, t = 2.27, d.f. = 86, $p = 0.03$). The age of the dog may also play a role, with respondents whose dogs were 12-23 months old having a more positive attitude than those whose dogs were less than 12 months old. There was also a trend towards more positive attitudes in respondents with male rather than female dogs, and in those with pure-bred dogs rather than mongrels, but none of these associations were significant at $\alpha = 0.05$.

There was some evidence to suggest that respondents' attitudes may influence behaviour towards and thus welfare of owned dogs, although in most cases this was not strong. Respondents whose dogs had never been vaccinated had a less positive attitude than those whose dogs had been vaccinated against rabies and distemper, but this association was only borderline significant (one-way ANOVA, $F_{2,137} = 2.17$, $p = 0.06$). A more significant difference was seen between the attitudes of respondents whose dogs were dewormed regularly or infrequently and those whose dogs had never been dewormed, with the latter group displaying a less positive attitude (one-way ANOVA, $F_{2,134} = 3.74$, $p = 0.03$). Respondents whose dogs had evidence of a skin condition (typically mange) also had a less positive attitude towards dogs than did people whose dogs were not affected (two-tail t-test: no condition mean = 86.0, skin condition mean = 78.3, t = 2.31, d.f. = 26, $p = 0.03$). Respondents' attitudes did not differ significantly on the basis of other indicators of welfare, including sterilisation, dipping, food type, feeding frequency, confinement, dog body condition score, evidence of lameness or fresh skin wounds, or the response to the owner when called.

6.3.4 Responses to individual items

Although the value of the item scale is in the combined response to all items, evaluation of responses to single items is also informative. Nearly three-quarters (72%) of all respondents said that if they had a female dog who had puppies, they would not want to keep them. Among only those respondents who in fact did own one or more female dogs, this figure was similar (75%). The majority of respondents said that the welfare of street dogs was important to them (63%), but few people liked having dogs around on their street (26%). Most people agreed that street dogs pose a danger to people (78%) and that they should not be allowed to breed (74%); however, 78% of respondents believed that it is not acceptable to kill dogs

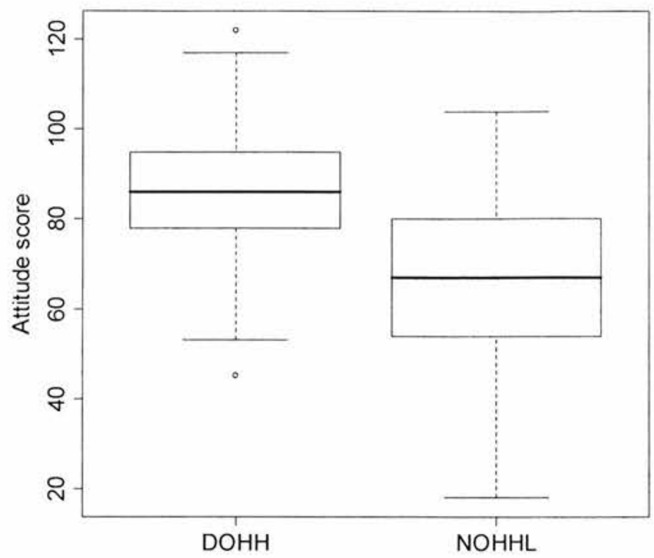


Figure 6.2. A box-plot showing the attitude scores of respondents from dog-owning (DOHH) and non-owning (NOHH) households. The bold horizontal line shows the median, the bottom and top of the box the 25^{th} and 75^{th} percentiles, respectively, and the whiskers 1.5 times the interquartile range. Points beyond this range are shown individually

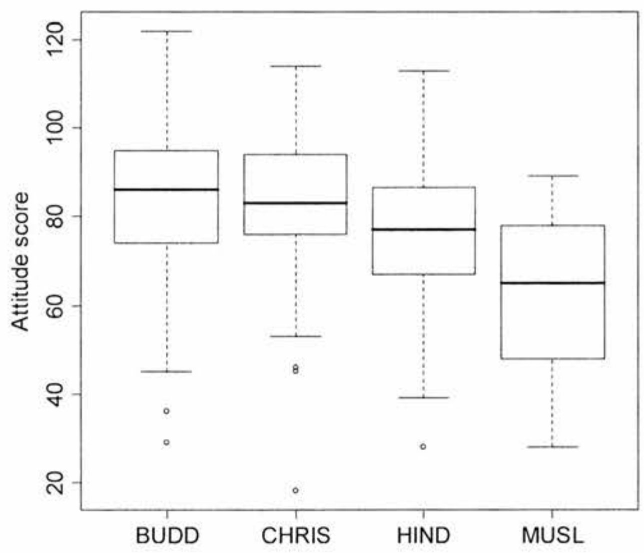


Figure 6.3. A box-plot showing the attitude scores of respondents from different religions. BUDD=Buddhist, CHRIS=Christian, HIND=Hindu and MUSL=Muslim. See Fig. 6.2. for a description of the components of the box-plot.

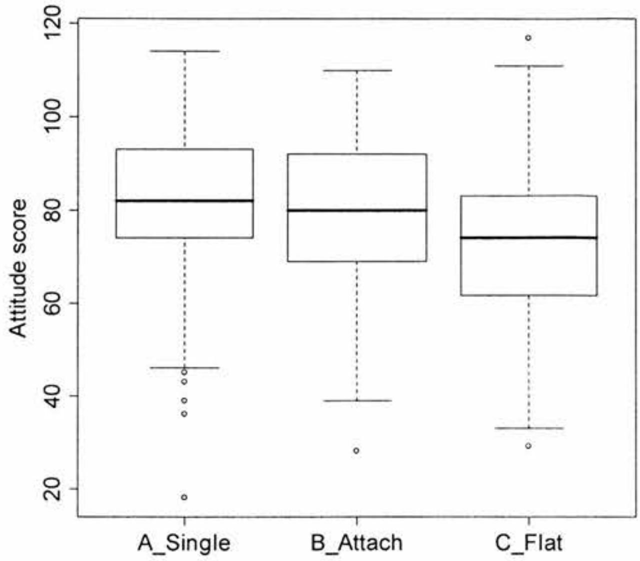


Figure 6.4. A box-plot showing the attitude scores of respondents from different housing types. See Fig. 6.2. for a description of the components of the box-plot.

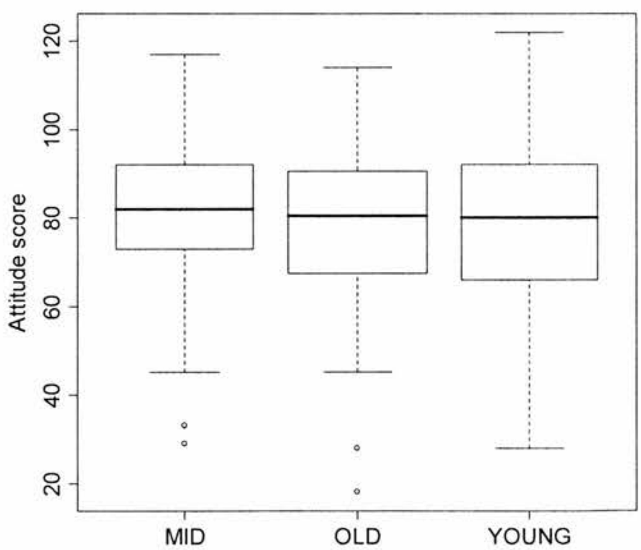


Figure 6.5. A box-plot showing the attitude scores of respondents from different age categories. MID=36-55 years, OLD= ≥56 years and YOUNG=16-35 years. See Fig. 6.2. for a description of the components of the box-plot.

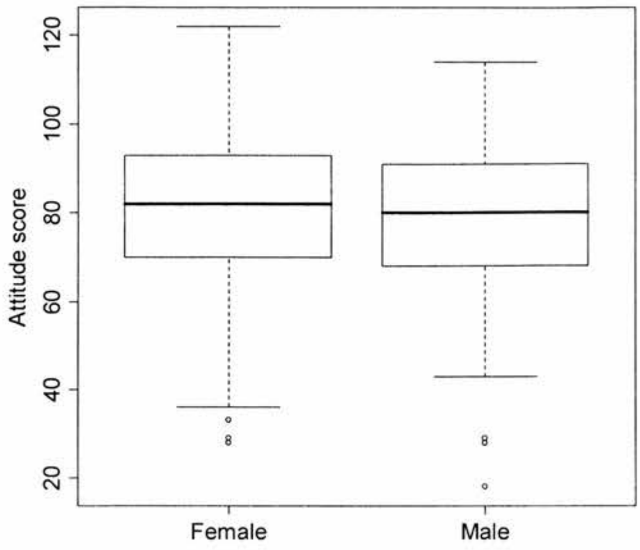


Figure 6.6. A box-plot showing the attitude scores of respondents of different genders. See Fig. 6.2. for a description of the components of the box-plot.

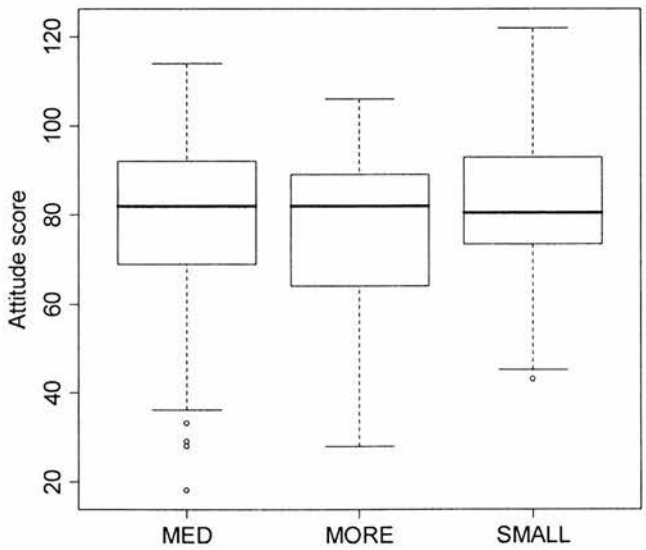


Figure 6.7. A box-plot showing the attitude scores of respondents from different household sizes. MED=4-6 occupants, MORE= ≥7 occupants and SMALL=1-3 occupants. See Fig. 6.2. for a description of the components of the box-plot.

6.4 Discussion

This study describes the development of a reliable and valid instrument for the measurement and evaluation of attitudes towards dogs in Colombo. It is one of the few such studies to take place in a developing country context, despite the potential value of such an instrument in informing policy decisions for dog population management and the control of rabies, a disease whose burden in developing countries far exceeds that in the developed world (Knobel *et al.*, 2005). For example, from the above it is clear that the killing of street dogs by the municipal council is extremely unfavourable to the community – so much so that such activities were found to engender antagonism towards the council's larger rabies control efforts (including a vaccination clinic at the local municipal pound). The finding that three-quarters of owners of female dogs would not want to keep any litters, together with a previous finding that less than a quarter of the owned female dog population is sterilised, suggests that dumping of (particularly female) puppies may well be supplementing the street dog population of Colombo. Further detailed studies of the drivers of owned and unowned dog population demography in this and other study sites are urgently needed to evaluate this hypothesis.

In order to have criterion-related validity, an item is required to have only an empirical association with some criterion or 'gold standard', and as such the term does not imply a causal relationship among variables; in fact, whether or not the theoretical basis for the association is understood is irrelevant to criterion-related validity. Construct validity, on the other hand, is directly concerned with the theoretical relationship of a variable to other variables. One method of establishing construct validity is so-called 'known groups validation' (DeVellis, 2003), which involves demonstrating that a scale can differentiate members of one group from another, based on their scale scores. The fact that owners have a significantly more positive attitude towards dogs than non-owners is an indicator of the construct validity of the attitude scale. This, together with the high measure of reliability, suggests that the scale may prove to be a valuable instrument in quantifying the impact of the WSPA/BPT/CMC programme, an important aspect of which is an education and awareness campaign to promote responsible dog ownership and improve attitudes towards maintaining the health and welfare status of dogs. This is part of a larger process whereby animal welfare agencies implementing humane dog population control programmes have begun identifying measurable indicators of success through which the achievements of a programme can be monitored and evaluated (International Companion Animal Management Coalition, 2007).

The association of religion and housing type with attitudes largely mirrors the effects of these variables on dog ownership (Chapter 5, this volume). The results of the multivariable analysis suggest that, among those variables included in this study, religion is the dominant predictor of people's attitudes towards dogs. Among dog-owning households however, attitudes towards dogs are not associated with the religion of the household. As with Chapter 5, future studies on this topic would benefit from a more in-depth examination of religious and cultural determinants (e.g. religiosity, ethnic group, language, etc) of perceptions and behaviour towards dogs.

Among single dog-owning households, there was some evidence of an association between respondents' attitudes and the level of care provided for household dogs, although this was not unequivocal. In particular the health status of dogs (as evidenced by the presence/absence of skin conditions), and the provision of veterinary services (vaccination and deworming), were associated with more positive attitudes. These findings are consistent with results obtained by Shore *et al.*, (2005), who found that pet attachment scores among American college students were related to 'standard' and 'enriched' care behaviours, but not to essential care such as the provision of food, water and shelter (i.e. even pet owners reporting low attachment provide beneficial care and attention to their pets). Within the socio-economic context of Sri Lanka, provision of veterinary services for dogs could plausibly be considered non-essential care. Similar results were obtained from a study on attitudes towards dogs amongst owners in Tanzania, where a significant but weak association was found between scores reflecting respondents' attitudes towards dogs as equals and the level of care provided for their dogs (Chapter 4, this volume).

6.5 Conclusion

A full understanding of the complex ecology of dog populations in urban environments, and subsequently of the effectiveness of humane dog population management programmes, requires a comprehensive, multi-disciplinary approach. Classic population ecology methods to ascertain the demographics of street dog populations must be adapted for use in highly heterogeneous environments, and supplemented by measures to understand the anthropogenic drivers of dog population dynamics. The attitude scale developed in this study, and the findings of the predictors and consequences of varying attitudes, provides a first step in addressing some of these issues in Colombo City.

Domestic dogs act as reservoirs and transmitters of rabies virus not only to humans, but also to other animals. The disease poses a threat to the continued survival of some of the world's most endangered canids. The following chapter presents data from an outbreak of rabies in Ethiopian wolves, and the response taken to bring the outbreak under control.

7 CHAPTER 7: TRAPPING AND VACCINATION OF ENDANGERED ETHIOPIAN WOLVES TO CONTROL AN OUTBREAK OF RABIES

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7.1 Introduction

Infectious diseases are important causes of population declines in wildlife. Over the last two decades pathogens have been identified as causes of population reductions or local extinctions in a wide range of taxa and habitats, including phocine distemper in seals (Heide-Jørgenson *et al.*, 1992), chytridiomycosis in frogs and toads (Daszak *et al.*, 1999), rabbit haemorrhagic disease (Villafuerte *et al.*, 1994) and crayfish plague (Alderman, 1996). Recent examples among carnivores include rabies in Blanford's fox *Vulpes cana* (Macdonald, 1993), African wild dogs *Lycaon pictus* (Gascoyne *et al.*, 1993; Hofmeyr *et al.*, 2004) and Ethiopian wolves *Canis simensis* (Sillero-Zubiri *et al.*, 1996), and canine distemper virus in black-footed ferrets *Mustela nigripes* (Williams *et al.*, 1988) and lions *Panthera leo* (Roelke-Parker *et al.*, 1996). Disease is a specific threat to small, fragmented or threatened populations, with viral diseases in particular responsible for high mortality or local extinction of several such populations (Murray *et al.*, 1999, Dobson & Foufopoulos 2001). These populations are vulnerable to pathogens that can infect multiple host species and that are typically transmitted from more abundant reservoir host populations (Murray *et al.*, 1999; de Castro & Bolker, 2005).

Although ecologists now acknowledge the role played by pathogens and their potential threats to endangered populations (see, for example, Scott, 1988; Daszak *et al.*, 2000; Woodford *et al.*, 2002; Kissui & Packer, 2004), in many instances managers of such populations remain ill-equipped to handle infectious disease outbreaks. Action is often hampered by a lack of detailed quantitative ecological and epidemiological data with which to undertake thorough contingency planning and objective risk assessment. Such risks include both those from the pathogen and from the intervention itself. Examples of the latter include possible stress-related responses, physical injury, vaccine-induced mortality (see for example Carpenter *et al.*, 1976; Durchfield *et al.*, 1990) or anaesthetic accidents. In addition, few disease-control interventions in endangered populations have been subject to a rigorous evaluation of the impact of such programmes, based on data collected before, during and after a disease outbreak. In some cases, the failure to effectively monitor and evaluate an intervention has generated considerable and damaging controversy (e.g. African wild dogs in the Serengeti ecosystem, see Burrows, 1992; Creel, 1992; Burrows *et al.*, 1994 & 1995; Creel *et al.*, 1997).

The evaluation of any vaccination-based disease control intervention should include an assessment of the protective effect generated by the vaccine in the target species, preferably under field conditions. Extrapolation from the immune responses seen in related species or captive conspecifics may be misleading (Woodroffe *et al.*, 2004). For example, prophylactic vaccination of African wild dogs through the administration of a single dose of inactivated rabies vaccine (effective in domestic dogs) has on several occasions failed to prevent the deaths of some animals from rabies (Kat *et al.*, 1995; Scheepers & Venzke, 1995; Hofmeyr *et al.*, 2000). However, empirical evidence suggests that multiple vaccinations may be effective in this species (Hofmeyr *et al.*, 2004).

Epidemiological theory recognizes the importance of heterogeneity arising from age-related, genetic, spatial or behavioural factors in the transmission of infectious diseases within populations (May & Anderson, 1984). Similarly, heterogeneity in immune response to vaccination between various population subgroups, as a result of differences in the proportion of hosts that become protected (vaccine 'take'), the degree of protection and the duration of immunity, has important implications for the design and efficacy of vaccination programmes (Halloran *et al.*, 1992; Woolhouse *et al.*, 1997). If vaccination can only be administered following the physical capture of individuals, as is the case for many wild species, differences in the 'trappability' (the probability of capturing an individual animal, e.g. Tuyttens *et al.*, 1999) of individuals in different segments of the population may give rise to an additional source of heterogeneity.

Ethiopian wolves persist in several small, highly fragmented populations (Marino, 2003) that are threatened by the repeated introduction of pathogenic viral diseases from surrounding domestic dogs (Laurenson *et al.*, 1997; Sillero-Zubiri & Marino, 2004, Randall *et al.* 2006). The largest of these populations, in the Bale Mountains National Park (BMNP), has suffered several dramatic declines as a result of mortality induced by epidemics of rabies (Sillero-Zubiri *et al.*, 1996a; Randall *et al.*, 2004) and canine distemper (EWCP unpublished report, see also Laurenson *et al.*, 1998). In 2003, rabies was again diagnosed in wolves in BMNP and an intervention based on the capture and vaccination of susceptible wolves was undertaken in an attempt to contain the outbreak. Here we describe the implementation and short-term outcome of the intervention in the BMNP Ethiopian wolf population, with particular emphasis on the immune response of

Ethiopian wolves to parenteral rabies vaccination and on the trappability (and hence protection) of different segments of the population. We then analyse the factors that may have contributed to the success of the intervention, and use these to underpin recommendations to conservation managers confronted with disease threats to endangered populations.

7.2 Methods

7.2.1 The outbreak

The Bale Mountains National Park, situated in south-central Ethiopia (6°54'N, 39°42'E), contains the largest remaining contiguous piece of Afroalpine habitat (Yalden, 1983), an ecosystem upon which the endemic Ethiopian wolves are reliant (Sillero-Zubiri *et al.*, 2004). Prior to 2003, BMNP harboured at least 300-350 of the global population of approximately 500 wolves (Marino 2003; Randall *et al.*, in press), largely in three linked sub-populations of relatively high density (Figure 7.1). A detailed description of the 2003/2004 rabies epidemic in the Ethiopian wolves of BMNP is given by Randall *et al.* (2004). Briefly, rabies was diagnosed on 28^{th} October 2003 from wolves found dead in the Web Valley since mid-August. A parenteral vaccination campaign of susceptible wolves was instigated, with the objectives of (i) containing the virus to the Web Valley, and (ii) reducing the BMNP population's extinction probability by protecting wolf packs in other key areas of the park. Trapping and vaccination started on the 13^{th} November 2003 in the Morebawa sub-population (Figure 7.1). The control phase of the intervention lasted until 14th January 2004, although further follow-up trapping sessions were conducted to assess the duration of antibody response. During the course of the intervention, 84 wolves were captured in over 5,200 trapping hours.

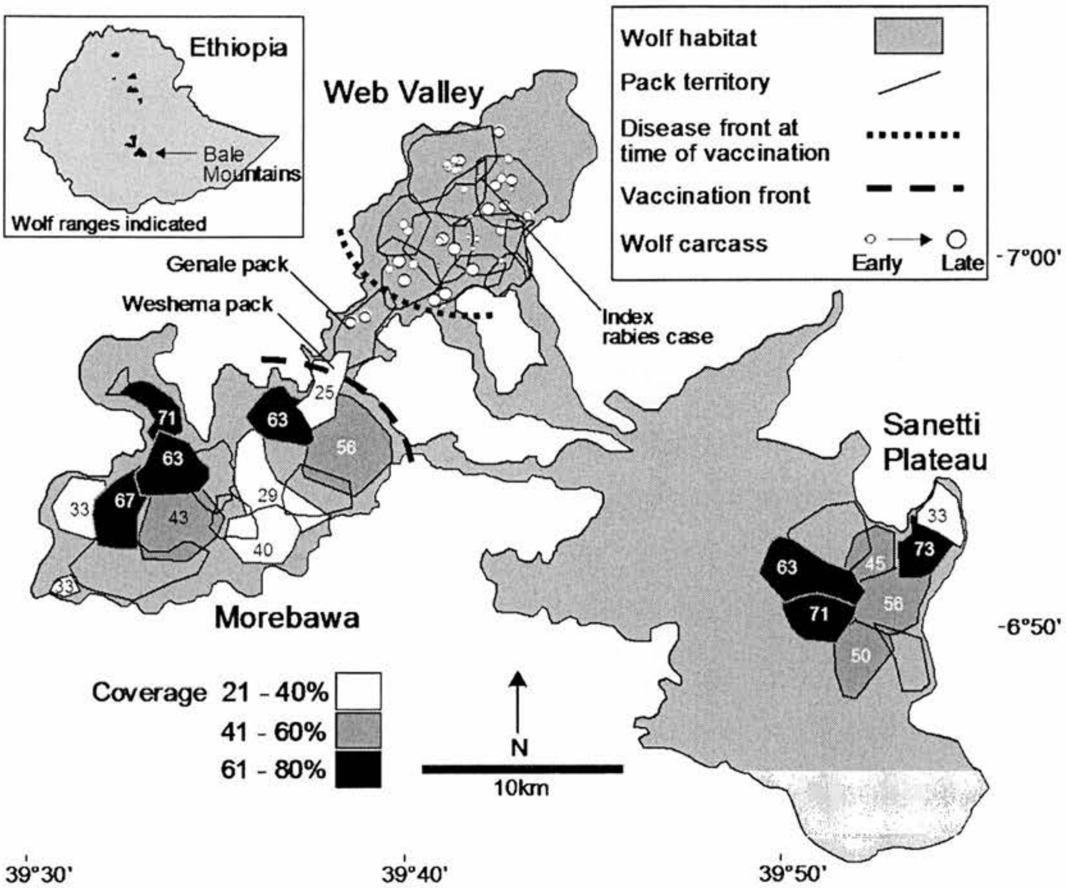

Figure 7.1. Map of the afro-alpine habitat in the Bale Mountains National Park, showing wolf pack territories in the rabies outbreak area (Web Valley) and the vaccination zones (Morebawa and the Sanetti Plateau). Figures show the percentage of each pack that was vaccinated during the control phase of the intervention.

7.2.2 The intervention

Wolves were captured using rubber-lined Soft Catch leg-hold traps (Woodstream Corporation, Pennsylvania, USA), following Sillero-Zubiri (1996). Three leg-hold traps were buried in a 1 m^2 trap-garden baited with meat, and three to six such gardens were placed within wolf pack territories in known, frequently-visited areas. Traps were checked every two to three hours during the day, and then at approximately 18h00, 22h00, 02h00 and 06h00. Wolves found in traps were covered with a blanket to induce passivity and allow physical restraint and subsequently immobilized using a combination of medetomidine (0.09 mg/kg, Domitor, Pfizer Animal Health, Pennsylvania, USA) and ketamine (1.5 mg/kg, Ketaset, Fort Dodge Animal Health, Iowa, USA). Anaesthetised animals were vaccinated intramuscularly with an inactivated vaccine, with alternate animals given either a 1 ml or 2 ml dose at a single site (Nobivac Rabies, Intervet, Milton Keynes, UK, batch nos. 79056A & 71032A), and marked using coloured ear-tags (Rototag, Dalton ID Systems, Oxon, UK). Samples collected from each animal included serum, whole blood in EDTA, saliva in phosphate-buffered saline (PBS), hair, a tissue sample from the ear pinnae stored in 96% ethanol and, when available, faeces in ethanol and 5% formalin. The weight, body measurements, and physical condition of all captured animals were recorded. One wolf in each of 12 packs (preferably an adult male when possible; adult females were not collared) was radio-collared to assist post-intervention monitoring. Long-acting antibiotics (300 mg amoxycillin, Clamoxyl L.A., Pfizer Animal Health) were administered to all wolves.

The effects of medetomidine were reversed using atipamazole (6.5 mg, Antisedan, Pfizer Animal Health) and animals observed until full recovery (no ataxia evident) or until lost from sight. Late pregnant females (as evidenced by swollen mammary glands) were not anaesthetised due to the risk posed to the foetuses. Such animals had serum collected and were vaccinated whilst held beneath a blanket. This procedure typically took less time than anaesthetic induction. Serum was extracted after leaving blood samples to stand for 24 hours, or after 12 hours if centrifuged, and split into at least two samples. Serum samples were kept cool in the field before being transferred to -20°.

7.2.3 Serology

Nineteen primary-vaccinated animals were recaptured 25 – 34 days after initial vaccination, to assess humoral immune response and to deliver a booster dose of 1 ml of vaccine. Further recapture efforts yielded serum samples from two primary-vaccinated animals and one boosted animal six months (154 – 188 days) post-vaccination, and four primary-vaccinated and one boosted animal at one year (344 – 373 days) post-vaccination. Blood was collected from recaptured animals whilst under physical restraint only.

Serum samples were sent to the Rabies Unit, Veterinary Laboratories Agency, UK. Both sets of serum samples from each animal were tested to ensure repeatability. All further analyses were based on the results of the first tests, unless otherwise stated. The fluorescent antibody virus neutralisation (FAVN) test was used for the detection of rabies virus-specific antibodies, as described by Cliquet *et al.* (1998). The FAVN test measures neutralising antibodies as a modality of a protective immune response following vaccination. A titre of 0.5 IU/ml is recommended by the World Health Organization (1992) as the minimum measurable antibody level in domestic dogs concomitant with seroconversion. The serum antibody titres were $\log_e$-transformed and the effects of volume (1ml, 2ml), batch (79056A, 71032A), sex (male, female) and age class (sub-adult/juvenile, adult) on antibody titres were tested using analysis of variance (ANOVA). Model simplification was done through backward deletion of non-significant terms ($P>0.05$), beginning with the least significant (Crawley, 2002). Studentized residuals were examined to detect possible outliers in the model (Belsley *et al.*, 1980).

7.2.4 Trappability

Factors affecting probability of trapping were assessed from the 0, 1 and 12 months trapping sessions. Fifteen packs (containing 116 wolves) were targeted initially with six of these packs (49 wolves) retargeted at one month. Four packs were targeted in the third session at 12 months, of which three packs (25 wolves) had been targeted on both previous occasions and one (6 wolves) which had been targeted only once. Thus 15 packs were trapped at least once, seven packs at least twice and three packs three times. Pack sizes and composition (age class and sex of pack members) at the time of trapping were known from population monitoring and behavioural observations made before, during and after the outbreak and intervention. (For a complete overview of population monitoring methods, see Sillero-Zubiri, 1994; Marino *et al.*, 2006; and Randall *et al.*, in press.) Individuals were classed as juveniles (≤ 12 months old), sub-adults (> 12 months but ≤ 24 months) or adults (> 24 months). 'Floater females' (dispersing adult females searching for breeding vacancies in packs, whose home ranges lie mainly in the interstices of established packs, Sillero-Zubiri & Gottelli, 1995) were also present in the population. Previous estimates that floater females constitute 7% of the population (Sillero-Zubiri & Gottelli, 1995) predicted the presence of eight floater females across the 15 trapped packs. Trapped wolves (n=9) that originated from packs other than the 15 targeted were excluded from the analysis; however, five wolves that originated from targeted packs and were trapped in the territories of adjacent packs were included. Trapping data were analysed for the effects of age class, sex and previous capture on the probability of capture and vaccination ('trappability') of wolves. This was initially done using chi-squared tests for unconditional associations, followed by fitting all variables in a generalised linear mixed model (GLMM) with a logistic link function, with pack fitted as the random effect (floater females were excluded from the GLMM as they do not form a discrete pack). Model simplification was done through backwards elimination. At the pack level I used data from the first trapping of each pack to examine factors affecting the proportion of wolves captured (using a generalised linear model with weighted regression and binomial errors, Crawley, 2002) and associated with the capture of at least one adult female in a pack (Fisher's exact test and univariate GLM with binomial errors). Predictor variables included pack size (range 6-11), territory size (range 352-1509 Ha; calculated as 99% minimum concave polygons, Lucy Tallents, unpublished), number of adult females in pack and trap-hours (with one trap-hour defined as one trap garden open for one hour). Finally, capture success rates at each trapping occasion were measured as the number of trap-hours per wolf caught (within target packs) and the proportion of wolves trapped in each pack. All analyses were conducted using R (version 2.0.1, The R Foundation for Statistical Computing, www.r-project.org) with $P \leq 0.05$ indicating statistical significance.

7.3 Results

7.3.1 The intervention

Sixty-nine animals were vaccinated between November 2003 and February 2004 during the control phase of the intervention: 36 and 33 from the Morebawa and Sanetti sub-populations respectively (Figure 7.1). An additional eight animals were vaccinated during the follow-up recapture phase (March – November 2004), and seven animals were sampled from the Web Valley outbreak area two months after the last carcass was found. Population coverage was 37% over 16 packs in Morebawa and 48% over nine packs in Sanetti. Seven packs (five in Morebawa and two in Sanetti) unknown at the time of intervention, were not trapped; however these wolves are included in calculations of overall population coverage.

7.3.2 Serology

Of the 77 wolves captured for the first time in the intervention zone, 74 were regarded as seronegative (rabies virus neutralising antibody titres <0.5 IU/ml) whereas three had titres of 0.87, 0.87 and 1.97 IU/ml. These latter were all seronegative when duplicate serum samples were tested (with mean titres across the two tests of 0.52, 0.69 and 1.07 IU/ml), suggesting that the initial seropositive results were due to variation in the FAVN test, a common occurrence at low titres (Briggs *et al.*, 1998). Of the seven animals captured in Web Valley post-outbreak, three tested seropositive (including on retest of duplicate samples, with mean values of 0.77, 1.56 and 5.92 IU/ml). The higher of these values could imply recent exposure to the virus (de Diaz *et al.*, 1975). A saliva sample from one of these wolves was negative for rabies virus RNA on RT-PCR, but other saliva samples collected were too degraded for analysis. Two of these animals were still alive one year later, while the remaining animal was last seen five months after sampling.

Analysis of antibody titres at one month post-vaccination showed that all 19 sampled wolves seroconverted (median = 4.50 IU/ml, interquartile range = 3.01-9.03 IU/ml). An initial ANOVA suggested a significant effect of volume on $\log_e$ neutralising antibody titres, with the 2 ml dose inducing a significantly higher titre (F=4.55, residual d.f.=17, P=0.048); however, the studentized residual for one of the observations was highly significant (maximal model: t=6.04, d.f.=14, P<0.001), and remained so when the model was refitted with titres derived from retesting of all 19 duplicate serum samples (t=3.58, d.f.=14, P=0.002). Excluding this animal, the ANOVA revealed a significant effect of vaccine batch on post-vaccination titres, for both the original (F=10.54, residual d.f.=16, P=0.005) and duplicate (F=7.55, residual d.f.=16, P=0.014) serum samples. This result may however be confounded by geographic and temporal factors that led to disparities in vaccine transport and storage conditions: the two batches were employed in separate areas with different logistic constraints, and the batch that induced the lower titres was used later in the campaign.

The effect of volume was no longer significant when included in the model with batch (F=2.16, residual d.f.=15, P=0.16), although animals vaccinated with 2ml of vaccine did have a higher mean titre than those that received only 1ml (6.48 IU/ml compared to 4.05 IU/ml). Neither age class (P=0.27) nor sex (P=0.56) had a significant effect.

Figure 7.2 shows the longevity of rabies neutralising antibody titres in primary-vaccinated and boosted wolves. At 180 days two wolves (one primary-vaccinated with a 2 ml dose, and the other primary-vaccinated with a 1 ml dose and boosted with a 1 ml dose at 30 days) were seropositive, with titres of 0.87 IU/ml and 0.66 IU/ml respectively. A third animal which was primary-vaccinated with 1ml but did not receive a booster was seronegative (0.29 IU/ml). Of the five wolves sampled approximately one year post-vaccination, the four that received only a primary vaccination were seronegative (of these, three animals had received 2 ml and one 1 ml). The single animal that received a booster dose after an initial 1 ml, was seropositive (3.42 IU/ml).

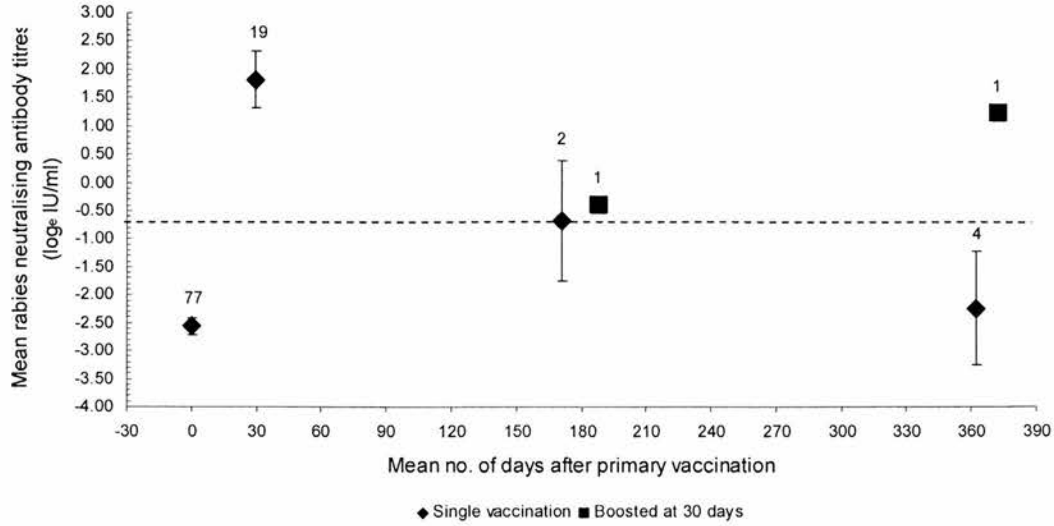

Figure 7.2. Mean rabies neutralising antibody titres (with 95% confidence intervals) of wolves that received a single injection with inactivated rabies vaccine on day 0 (primary-vaccinated ◆) and those that received a booster dose at approximately 30 days (boosted ■). Dotted line shows the adopted cut-off for seropositivity (0.5 IU/ml). Figures above the symbols are the number of wolves in each group.

7.3.3 Trappability

Males had higher odds of capture than females at first trapping (χ^2=4.34, d.f.=1, *P*=0.04, odds ratio=2.33, exact 95% CI=1.11 to 4.86), although this association was no longer significant if floater females (none of whom were captured, and whose existence was extrapolated from previous studies) were ignored (χ^2=1.69, d.f.=1, *P*=0.19). There was no association between age-class and trappability, whether floater females were included (χ^2=0.89, d.f.=1, *P*=0.35) or excluded (χ^2=0.30, d.f.=1, *P*=0.59). These results held in the GLMM, with neither age-class, sex nor their interaction found to be significant (*P*>0.15). The estimated variance of pack random effects in the GLMM was small (0.0004). The odds of being trapped on the second trapping occasion were greater for animals captured in the first trapping session (GLMM: t=2.26, d.f.=44, *P*=0.03, odds ratio=3.96, exact 95% CI=1.20 to 13.04). However the probability of an animal being captured a third time was not associated with it having been captured on the first (*P*=0.13), second (*P*=0.48) or either previous (*P*=0.34) trapping occasion. The effect of trapping occasion on capture success rates is shown in Figure. 7.3.

Pack size, territory size and trap-hours were not significantly associated with the proportion of wolves captured within a pack (*P*>0.37). In six of the 15 target packs no adult female was trapped. An adult female was more likely to be trapped when there were two or more adult females in the pack (8/8 vs. 1/7, Fisher's exact test: *P*=0.001). The probability of capturing at least one adult female was not significantly associated with total pack size (*P*=0.84), trap-hours (*P*=0.78) or territory size (*P*=0.09).

7.3.4 Effect of intervention on rabies outbreak

The last known rabies case was found in the Web Valley on the 30th January 2004. Two carcasses were recovered on the 18th and 22nd November 2003 in the isthmus pack connecting the Web Valley to the Morebawa sub-population (Figure 7.1), and seven of eight individuals disappeared from the adjoining Weshema pack in Morebawa some time shortly after 17th January 2004. This Weshema pack had not been identified at the time of the intervention, although two pack members were vaccinated in adjacent territories. Of these, one individual who was vaccinated on 13th December 2003 disappeared after being re-sighted on the 7th January 2004. The only surviving individual received 2 ml of vaccine on the 15th November 2003, in the first week of the intervention. Despite increased levels of surveillance no other rabies-related deaths were detected in the intervention areas. In contrast, 40 carcasses were found in the Web Valley and surrounding areas during the course of the outbreak, and another 36 wolves disappeared in addition to the seven from Weshema, a total mortality of 76% in the Web Valley sub-population (Randall *et al.*, 2004).

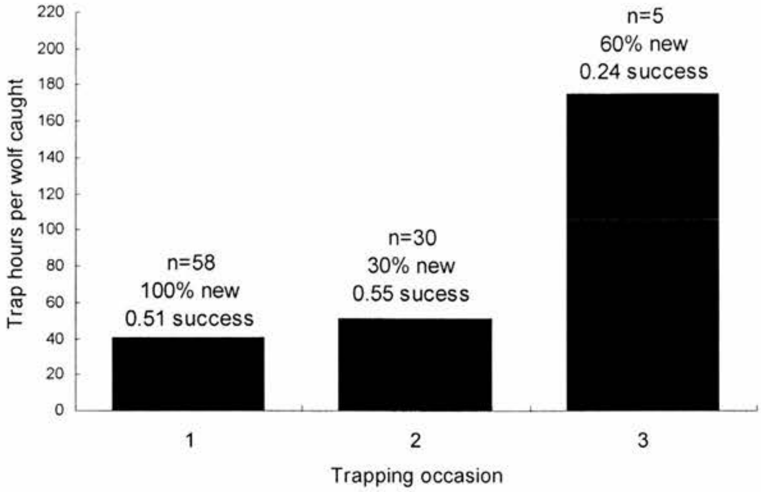

Figure 7.3. Graph showing capture success rate as a function of the number of times packs were trapped. Figures above the graph show the number of wolves trapped (n), the percentage of wolves trapped that had not been trapped on any previous occasion ('% new') and the number of wolves trapped as a proportion of all wolves present within targeted packs ('success').

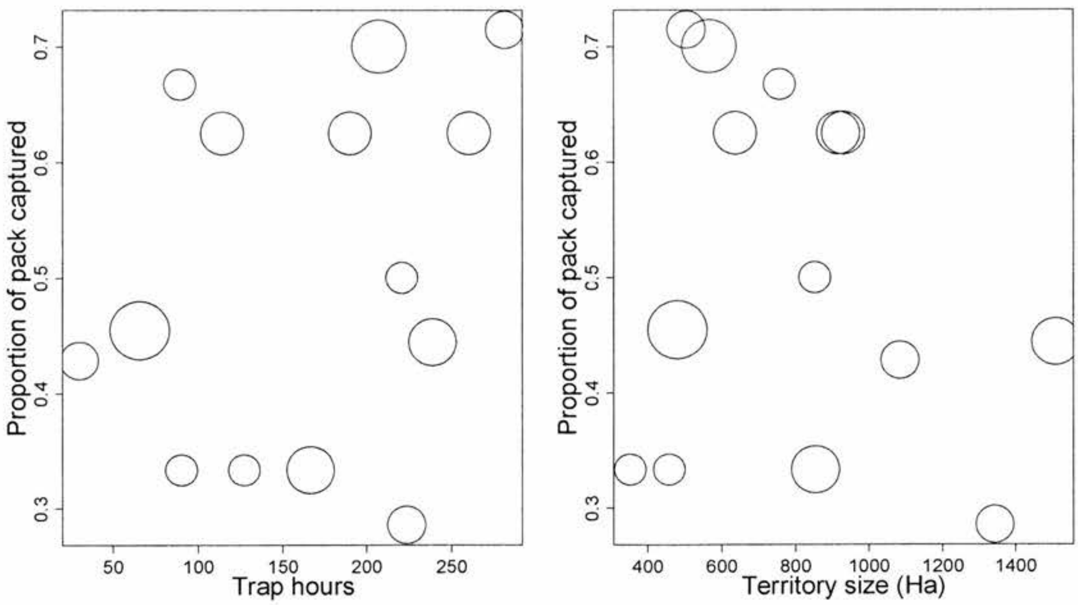

Figure 7.4. Graphs showing the proportion of wolves captured from within packs as a function of the number of trap hours (left) and pack territory size (right). The size of the plotting symbols is proportional to the size of the pack.

7.3.5 Risks to target and non-target species

During the intervention, 114 capture events occurred in over 5,200 trap-hours, with a capture event defined as the capture and sampling of a wolf. This definition thus includes animals re-caught in further trapping sessions but excludes 'trap-happy' animals re-caught within the same trapping session who were not re-sampled. Two capture events resulted in injury: one animal suffered a complete, uncomplicated fracture of the right tibia and fibula during physical restraint when two wolves were caught simultaneously, and a trap-inflicted injury to another wolf necessitated amputation of the medial digit of the right forefoot at the first interphalangeal joint. Both wolves were released and were still alive one year after capture. All but three captured wolves were alive six months after capture, a rate consistent with background mortality estimates (Randall *et al.*, 2004). A full analysis of differential survival rates between handled and unhandled animals is underway. Trapping had minimal impact on non-target species: eight raptors (*Aquila* spp.) were caught in traps and released without evident injury, while one Starck's hare (*Lepus starcki*) was euthanized due to a trap-induced femoral fracture. Six domestic dogs found in traps were vaccinated at the BMNP's request and released without incident.

7.4 Discussion

This paper presents several strands of evidence through which the success of the intervention can be assessed and general recommendations made. First, valuable information on the response of Ethiopian wolves to inactivated parenteral rabies vaccine was obtained. All 19 wolves recaptured one month after vaccination exhibited serum neutralising antibody titres well above the accepted level of seroconversion. Of the wolves sampled one year after vaccination, the only individual with a high titre had received a booster dose of 1ml at one month post-vaccination (Figure 7.2). These results are comparable to the magnitude and duration of antibody responses reported in domestic dogs (Mansfield *et al.*, 2004). Doubling the 1 ml dose (recommended for domestic dogs) at a single injection site did not produce significantly higher initial antibody titres in Ethiopian wolves at one month, nor did it appear to improve the longevity of antibodies, although sample sizes are very small. Given these results, and that the immune response of Ethiopian wolves appears similar to that of domestic dogs, a prophylactic vaccination protocol of 1ml of inactivated vaccine, with a booster one to six months later, is advisable. Further boosters would undoubtedly be required to maintain immunity for life, although it should be noted that dogs are still protected against rabies virus challenge for 22-36 months after vaccination (Wandeler, 2006), indicating that even in the absence of neutralising antibodies, individuals can mount a protective anamnestic immune response upon challenge.

The presence of three unvaccinated, seropositive wolves in the outbreak area raises the possibility that these animals may have survived exposure to the virus. It is speculated that this exposure was to a low dose of virus by non-bite transmission, most likely through the mucous membranes following oral-oral contact with an infected animal (Constantine, 1962; Dutta, 1998; Fooks *et al.*, 2006). It is further plausible that the individual in the sample of 19 wolves (trapped outside the outbreak area) whose humoral immune response to vaccination was significantly higher than that of the others may be just such a survivor who, although seronegative at the time of vaccination, retained sufficient immunologic memory from a previous exposure to mount a substantial and rapid humoral response to the vaccine.

Understanding the factors affecting the probability of capturing at least one adult female in each pack is important as this may affect population recovery rates. In Ethiopian wolves, as in other co-operatively breeding canids, reproduction is essentially restricted to a single dominant female in a pack (Sillero-Zubiri *et al.*, 1996); therefore the pack (as defined by the presence of at least one reproductively-capable female and male) is considered the fundamental breeding unit in the population. This has implications for population recovery following an epidemic: Marino *et al.* (2006) reported an inverse density-dependent growth rate in the Web Valley following the rabies epidemic there in 1992, with low population growth rate at low wolf densities most likely due to the extinction of two of the five study packs (although the possibility of an Allee effect (Courchamp *et al.*, 1999) resulting in increased adult mortality or decreased juvenile recruitment within small packs was not ruled out). Failure to trap and vaccinate an adult female in a substantial proportion of packs, and failure to vaccinate any floater females who may otherwise have been able to fill breeding vacancies, may retard population recovery and keep populations at a level where they remain vulnerable to additional stochastic perturbations. Even if the pack continues to defend a territory, the loss of adult females could delay breeding until any surviving sub-adult females reach reproductive maturity. However, the validity of this hypothesis requires further investigation, as it will depend on the pattern of mortality seen in partially-vaccinated packs, and on the response of a pack to the loss of its adult females. The interactions between number of adult females in a pack, territory size and quality, and juvenile recruitment, and their implications for post-epidemic population recovery, also warrant further scrutiny.

The positive association between the probability of a wolf being trapped on the first and again on the second trapping occasion suggests that wolves may be inherently 'trap-happy' or 'trap-shy', such that repeated captures over time will yield the same individuals. While the trapping experience is almost certainly highly stressful, the sedation of animals with an agent known to cause a degree of retrograde amnesia (ketamine, Saha *et al.* 1990) may inhibit any potential deterrent effect. The lack of a similar association between the probability of capture on the third and any previous occasion and the marked decline in capture success between the second and third trapping sessions could be explained by the fact that wolves were not anaesthetized when trapped a second time, although sample sizes are small (Figure 7.3).

All available empirical and theoretical evidence (Haydon *et al.*, 2006) suggests that this intervention was effective in halting the spread of the outbreak. Rabies mortalities were recorded in all territories in Web Valley and the isthmus, up to the main vaccination area in Morebawa. The extent of the eastward spread of the virus towards the Sanetti Plateau is unknown, although no rabies-confirmed deaths occurred within the surveillance area there. Despite this success, and the minimal short-term impacts on the population, we believe that the adopted course of action was only justified in the face of a large-scale outbreak. Less invasive and more sustainable methods such as the use of oral vaccines are highly desirable and should be developed and tested as tools for future use, either prophylactically or during outbreak situations. The high prevalence of rabies in the surrounding domestic dog population and the apparent frequent incursion of rabies into the BMNP wolves, makes the development of an effective oral vaccination protocol all the more urgent.

7.5 Recommendations

Our experience in managing this outbreak leads us to suggest a number of recommendations that may be useful to other managers faced with disease epidemics in endangered populations. First, we are aware that the long-term population monitoring performed by the Ethiopian Wolf Conservation Programme was fundamental to the initial rapid detection of the outbreak and to the intervention outcome. The EWCP supplied valuable demographic and surveillance data and a team of experienced and dedicated field staff who were integral to the implementation of the intervention and post-intervention monitoring. Clearly, in other situations, an existing monitoring system and experienced management team will assist any disease control programme and thus efforts should be made to ensure such expertise and programmes are in place.

Second, potential tools for disease control should be investigated and assessed, and risk analyses and predictive modelling of management options carried out in advance, where possible. In this regard we were assisted by existing theoretical models (e.g. Haydon *et al.*, 2002) and action plans (Laurenson *et al.*, 1997), stemming from the pre-existing knowledge that domestic dog diseases pose a threat to these Ethiopian wolves. However, oral baiting and vaccination trials had not been carried out, although permission had been requested. Managers of threatened species where the disease risk has not been identified or explored, should perhaps devote more effort to risk assessment and contingency planning for disease outbreaks.

Third, when considering an intervention programme, and with the potential controversy of such an approach, we suggest that it is essential to carefully design both the intervention itself and post-intervention monitoring, in order to maximise the information gained for that and future intervention programmes. The capacity and resources for population monitoring after intervention and the data required for subsequent outcome analysis should be carefully considered. In some situations, it may be that additional procedures that involve more handling will be necessary to assess the effectiveness of the intervention. These issues have financial and human resource implications, and must be built into emergency funding budgets. In addition, expert opinion should be canvassed so that policy can be decided in advance, although the details of each outbreak situation may preclude firm policy decisions in some cases. We therefore recommend that contingency policy, decision trees and plans be developed before a problem arises so that the course of action is already laid out for decision making and intervention as required.

Fourth, we acknowledge that previous discussions, debates and failures greatly assisted our approach to the intervention. Such discussion has stimulated a more rigorous approach to disease management problems and has generally driven forward the issue by increasing general awareness, although in some situations, misunderstanding of the issues has led to lack of decision-making. Thus we suggest that maintaining discussion and disseminating information, such as that gained in this outbreak, in accessible literature is crucial in enlightening debate and improving future decision-making in the face of wildlife disease outbreaks.

An integrated and collaborative approach is now essential to studying and controlling pathogens that affect wildlife. With ecological, behavioural, political and human socio-cultural factors all having an effect on transmission and spread of disease, control programmes need to address all these aspects if they are to have a chance of success. We suggest that linkages with institutional and government authorities, including laboratories and other experts should be in place prior to the occurrence of an outbreak. With increasing restrictions on shipping samples due to bioterrorism threats, developing and maintaining quality local or regional diagnostic laboratories must also be a priority.

In conclusion, we hope that this case study and our experience-based recommendations will encourage wildlife researchers and managers to collect and present data on disease management interventions. Only with a balanced understanding of the risks involved, and by learning from interventions and their consequences, can a considered, multi-disciplinary approach to disease management in wildlife populations be achieved We strongly recommend that all efforts are made to carry out a priori, both risk assessments and research into the feasibility of disease control methods.

8 SYNTHESIS AND CONCLUSIONS

Rabies, one of the oldest diseases known to man, remains uncontrolled in many parts of the world. This is in spite of the availability of safe, effective and economical tools for its control. The wide-spread distribution and rapid growth of its primary reservoir host population in the developing world, the domestic dog, together with their ubiquitous association with human populations, explains why canine rabies is endemic across much of the globe. However, given that effective dog vaccines are available, and that rabies has been eliminated from dog populations in many countries (including large, non-island countries like the United States) through the implementation of these vaccines and other control measures, why does the disease continue to exact such a toll in other countries? One reason must be a lack of political and institutional will to tackle the problem. This in turn is based in part on a lack of awareness of the extent of the problem, coupled with competing interests for scarce public health resources. Reliance on the reporting of rabies cases via official channels may lead to underestimation of the true incidence of the disease by up to one hundred-fold, and a subsequent lack of prioritisation of resources for its control. This leads to a vicious circle of neglect – low priority means no resources available for surveillance, which in turn ensures that the true extent of disease occurrence remains unknown. It is hoped that the quantitative estimates of rabies burden presented in Chapter 2 will redress this, and provide impetus for policy makers and donors to tackle the problem. One advantage of the quantitative risk assessment method used in Chapter 2 is its transparency – as more detailed data become available so the model can be updated and refined. Knowledge of the estimated burden of the disease, together with preliminary data which shows that, in terms of cost per DALY saved, rabies is among one of the most cost-effective diseases to target (through the mass vaccination of dogs), have already encouraged international health agencies and donors to reconsider their prioritisation of this disease. In this respect, further research is needed to develop more refined models of cost-effectiveness estimates across different time horizons and under different epidemiological scenarios.

An additional reason for the lack of rabies control in much of the developing world is that, while safe and cheap dog rabies vaccines are available, their effective implementation is often hampered by an incomplete understanding of the demographics and ecology of dog populations in rabies-endemic areas, and the relative roles of anthropogenic and non-anthropogenic regulatory factors. Accurate estimates of dog population numbers are rarely available, and existing estimates often grossly underestimate actual numbers of dogs. Chapter 3 provides a means whereby such numbers can be extrapolated for a variety of socio-cultural scenarios in Tanzania (including national estimates based on composite dog-human ratios), while at the same time highlighting the difficulties encountered in the estimation process (particularly the lack of sampling frames for households in the estimation of the owned dog population). National estimates of the owned dog population, derived from the work presented in Chapter 3, will be included in the national rabies control policy document currently being developed by the Tanzanian government, and have also been included in funding applications to donors to support this programme. These figures can be used to estimate required resources for rabies control efforts, and to allow the optimal utilisation of those resources. They can also serve as targets against which vaccination efforts can be measured, to assess the vaccination coverage achieved.

Humane dog population management programmes can serve as a valuable adjunct to vaccination efforts in the control of rabies, by decreasing dog population growth rates and reducing population turnover. Such stable populations greatly reduce the frequency of mass vaccination campaigns needed to maintain a given level of vaccination coverage, in addition to reducing (over time) the total number of dogs to be vaccinated. Chapter 5 provides valuable baseline data for an humane dog population control programme aimed at the sterilization of owned dogs in Colombo, Sri Lanka, and together with Chapter 3 provides a basis for comparison of owned urban dog populations in Asian and African environments. The characteristics of dog-owning households identified in these two chapters will enable the effective targeting of education and awareness campaigns, for both humane dog population programmes and rabies vaccination campaigns. The strong male bias identified in this study in the sex ratio of owned dogs, together with the preference for male dogs and the fact that few owners of female dogs would want to keep a litter, point to the existence of possible anthropogenic drivers of the population dynamics of both the owned and unowned dog population in Colombo. Further work is needed to understand the effect of these drivers, and their interaction with non-anthropogenic regulators. Such studies would need to examine the fecundity and sex-specific pup survival in both the owned and unowned segments of the dog population, and migration between the two sub-populations, through adoption or abandonment. This work is necessary to understand the effect of humane dog population control programmes on dog population dynamics, and could be done in conjunction with studies on the impact of these programmes on the long-term cost-effectiveness of dog vaccination campaigns.

Human behaviours which impact on the dynamics and welfare of dog populations are expressed as a result of the underlying attitudes of individuals towards dogs. These attitudes are in turn modified by socio-cultural conditions and individual experience. Chapters 4 and 6 present unique research into these attitudes and modifiers in a cross-section of inhabitants in Tanzania and Colombo. Building on the work done in Tanzania, the item scale developed in Chapter 5 provides a valuable tool with which these attitudes, and their relationship to dog welfare and rabies control, can be further explored. For example, the finding that household heads with more positive attitudes towards dogs were more likely to have their dogs vaccinated at a central point suggests the need for integration of programmes on responsible pet ownership into rabies vaccination planning. Overall, the work suggests a more positive affective attitude towards dogs in these countries than was perhaps previously supposed, and that this particular aspect of the human-animal interface may be worthy of further study. The effect of these attitudes, and the possible changes in attitude occurring as a result of the implementation of responsible pet ownership programmes, on the uptake and impact of the humane dog population control programme in Colombo, is a potentially fruitful area for further research.

The application of the findings presented in this thesis to the refinement of vaccination campaigns for the control of canine rabies will be of benefit not only to the fields of public health and animal welfare, but also to the conservation of endangered canids threatened with spill-over of the disease from sympatric dog populations. The management strategies discussed in Chapter 7 for the reactive vaccination of Ethiopian wolf populations following such a spill-over event, although effective, are costly and potentially high-risk if implemented too late. Targeted vaccination of the dog population, ideally in conjunction with responsible pet ownership and humane population control programmes, may be more effective, and have the additional benefit of improving relations with local communities by reducing the incidence of human bites from suspect rabid dogs. Once again attitudes of owners towards dogs play a role, as the uptake and cost-effectiveness of these vaccination programmes is dependent on owner co-operation and influenced by the ability and willingness of owners to handle their dogs. Understanding these attitudes and their effects on owner behaviour may improve delivery of vaccines, possibly through the deployment of new technologies such as bait formulations containing oral rabies vaccines.

Statement to communities:

"Rabies is a disease which is transmitted to humans through the bite of a rabid dog. Children are often the ones affected. The disease can be controlled in dogs by vaccination. People who own dogs must be encouraged to get them vaccinated against rabies. If a rabies vaccination campaign is organised in your community, households with dogs should take them to the central point to receive the injection. Dogs should also be kept confined to prevent them roaming. Female dogs should also be sterilised if possible, to prevent the dog population from growing too large"

Statement to policy makers:

"Each year, around 55,000 people in Africa and Asia die from rabies, an entirely preventable disease. The burden of rabies alone in these areas is equivalent to that of Japanese encephalitis, dengue fever and river blindness together. However, official statistics underestimate rabies deaths in humans by up to 100 times. Rabies can be controlled through the vaccination of domestic dogs with an injectable vaccine. The numbers of dogs to be vaccinated can be estimated from the numbers of people in urban and in rural areas. It is important to have these estimates to allow for proper planning and evaluation of rabies vaccination campaigns. In general, 70% of all dogs should be vaccinated to prevent outbreaks of rabies."

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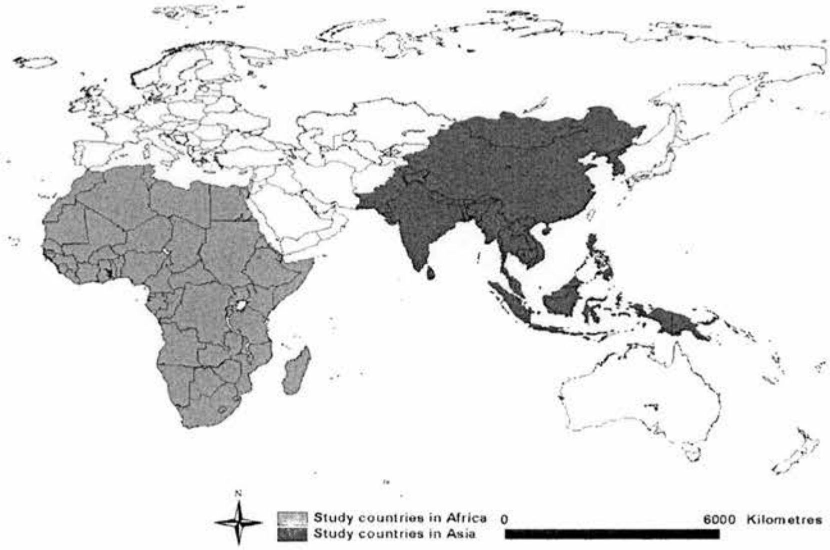
APPENDIX 1 List of countries included in the burden of rabies study (Chapter 2)



AFRICA
Algeria
Angola
Benin
Botswana
Burkina Faso
Burundi
Cameroon
Central African Republic
Chad
Congo
Cote d'Ivoire
Democratic Republic of Congo
Djibouti
Egypt
Equatorial Guinea
Eritrea
Ethiopia
Gabon
Gambia
Ghana
Guinea
Guinea-Bissau
Kenya
Lesotho
Liberia
Libya
Madagascar
Malawi
Mali
Mauritania
Morocco
Mozambique
Namibia
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
Somalia
South Africa
Sudan
Swaziland
Togo
Tunisia
Tanzania
Uganda
Zambia
Zimbabwe

ASIA
India
China
Bangladesh
Bhutan
Brunei
Cambodia
Democratic Peoples' Republic of Korea
Indonesia
Lao's Peoples' Democratic Republic
Malaysia
Mongolia
Myanmar
Nepal
Pakistan
Papua New Guinea
Philippines
Republic of Korea
Sri Lanka
Thailand
Viet Nam

APPENDIX 2 Reference sources for parameter estimates provided in Tables 2.1-2.4

Appendix 2a. Reference sources for human:dog ratio estimates (Table 2.1)

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